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Toward Consistent Creation of Marine Information Overlays: Configuration of ESRI's PLTS Nautical Solution

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ABSTRACT

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This project presents a set of tools to facilitate interoperability between an ArcGIS geodatabase model and the S-57 international standard for nautical data. Additionally configurations and workflows were developed for consistent creation of nautical data in accordance with said standard. Central to this interoperability are Marine Information Overlays (MIO), which are additional navigation information to the Electronic Nautical Chart database. MIO data is intended to provide safe and efficient ship routing. Semantic mapping between the marine objects in the S-57 standard and the MIO model preserves the essential components of each. Data interoperability is realized through the use of semantic mapping via a configured PLTS Nautical Solution import/export engine and standards are supported through the use of this software.

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List of Acronyms

CASE	Computer Assisted Software Engineering
CHRIS	Committee on Hydrographic Requirements for Information Systems
ECDIS	Electronic Chart Display Information System
ENC	Electronic Navigational Chart
GIS	Geographic Information System
HGMIO	Homogenization Group on Marine Information Overlays
IHO	International Hydrographic Organization
MEP	Marine Environmental Protection
MIO	Marine Information Overlay
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
PLTS	Production Line Tool Set
UML	Unified Modeling Language
XML	Extensible Mark-up Language

1. Introduction

Digital information has become an essential part of everyday life. To quote business executive William Pollard on information, “unless it is organized, processed, and available to the right people in a format for decision making, it is a burden, not a benefit.” This project makes strides to fulfill the need for useful data. It centers on making coral reef and marine protected area (MPA) data more organized, consistent, and available to marine conservationists, mariners, and a variety of other decision makers.

This project examines and extends the current abilities of the Environmental Systems Research Institute’s (ESRI) products that are designed for creating marine information products. These products are used by mariners and conservationist among others for decision support. In order to deal with the consistent production of this data, this project focuses on three aspects of ESRI products for extension or modification: the Electronic Navigational Chart (ENC) data model; the data interoperability capabilities between the native ENC data format (S-57) and ESRI’s geodatabase; and the data management and maintenance capabilities of ArcGIS Production Line Tool Set (PLTS) Nautical Solution. Each of these aspects is discussed more thoroughly in the paragraphs below.

1.1. The Big Problem

Preserving coral reef environments is essential due to the plethora of services they provide to us at the local and global scale including shoreline protection, erosion prevention, fisheries, and nutrient cycling (UNEP, 2006). Since the start of ocean travel, there have been many ways to convey information about oceans risks, resources, and services. Historically the medium of choice has been paper charts. However technological advances of the 20th and 21st centuries such as Global Positioning System, video monitors, Electronic Navigation Charts, and Electronic Chart Display and Information System (ECDIS), are gradually replacing paper maps and charts as navigation aids and resource identification vectors. With these advances it is now possible to disseminate hydrographic data in greater detail regarding features of interest for navigation and conservation to ocean-going vessels. However, the increase in available information about oceanic environments and phenomenon is not always appropriately represented as standardized digital hydrographic objects. This discrepancy can hinder navigation, resource management, and resource exploration efforts.

To put the problem into context of this project, there are two issues: the need for additional marine information, specifically coral reef and marine protected areas, for use by ships, marine conservationists, and decision makers; and the current shortcomings of standards and software products to handle new marine product production, management, and maintenance.

Nautical charts are composed of features meant to provide detailed information for ship navigation. With thousands of boats traveling the oceans and seas, this information is critical for safety at sea. These vessels can cause harm to ocean environments such as coral reefs through running aground, anchoring, and tank dumping. Providing mariners with additional coral reef and MPA data will give them tools to make better decisions and become better stewards of the environment. This data would also “assist mariners to navigate safely and avoid environmental damage by providing relevant information in a format which an ECDIS could be adapted to use" (National Oceanic and Atmospheric Administration, 2007).

Adding marine conservation-specific features and attributes will allow conservationists to record, transfer, and present environmental monitoring data in a standard format and representation. Creating and disseminating this additional data will "support the protection and sustainable use of the marine environment" (National Oceanic and Atmospheric Administration, 2007).

Software solutions for the creation of ENC data and ENC cells have already been developed by several companies including ESRI. In order for these companies to adapt to the changing demands of their clients (i.e., the creation of additional marine products) the companies software needs to be adaptable and extendable. With NOAA submitting proposals for additional marine product specifications, companies that currently support the effort of creating ENC cells need to be ahead of the game. Preparing the data models and software for additional marine product- known as Marine Information Overlays or MIO- essential to stay ahead of the curve and provide timely and effective solutions. At this time the software is not equipped to create these new products and needs to be configured to do so.

1.2. Client

ESRI's Global Navigation team is the client for this project. This group is responsible for implementation and support services for domain-specific solutions. Specifically, the group caters to the aeronautical, nautical, military, and topographic domains. Global Navigation strives to provide support and solutions to organizations looking to streamline their data production routines. Through the use of industry-leading tools, this team has the capability to implement and support standards-driven data production and end products. Two contacts were designated: Rafael Ponce and Andy Ommen.

Rafael Ponce acted as the sponsor for this project and was the main point of contact. Ponce has recently joined the Global Navigation team at ESRI. His former post at the Mexican Hydrographic Office and involvement with the MIO standard, and discussions at the IHO made him uniquely qualified for his role in this project.

Part of Mr. Ponce's role was to provide ENC datasets for testing and proof of concept of the application. This data was used as a case study to show the resolution of the problems documented in section 1.3. This information served as the base dataset for showing proof of concept of MIO creation and maintenance using ArcGIS and PLTS Nautical Solution. Mr. Ponce provided feedback and validation of key deliverables throughout the project as well as documentation on the standardized workflows currently used to create ENC data and ENC cells. These were used to aid in the creation of workflows that are in line with current standards.

Andy Ommen served as the technical advisor. Mr. Ommen has worked on the development, implementation, and support of the PLTS Nautical Solution. As such he, too, is uniquely qualified for his role. Mr. Ommen provided several key parts of the project including current database models, knowledgebase tables, product XML files, additional PLTS databases, and timely support.

1.3. Statement of the Problem

A Marine Information Overlay (MIO) is considered to be "supplementary information needed by the mariner" (Nelson, 2003). This data can be used for many purposes, but the overarching purpose is that of a decision support tool. This information should not interfere with the primary decision support tools it is being used with, i.e. ENC. Ensuring MIOs are standardized, consistent, properly geometrically coincident, and do not interfere with ENCs or navigation is the problem this project worked to solve. In order to do so, a preliminary standardized Marine Environmental Protection (MEP) MIO specification sheet needed to be produced (built on the NOAA MEP encoding guide) and ESRI's PLTS Nautical Solution needed to be extended.

Development of an MIO product encoding guide is essential for standardized and consistent creation of MEP MIOs. The encoding guide defines and documents all aspects of an MIO: objects, their representations, allowable attributes, and attribute domains. This encoding guide was essential to move forward with standardized creation and consistent production of MEP MIOs. Another problem is how to implement the contents of the draft encoding guide created by NOAA and extended on for this project using ESRI products for consistent data creation.

As with most spatial data, coral reef and marine protected area MIO data need to be maintained in order to provide accurate and up-to-date information. Geographic information systems (GIS) give the ability to import and export, create, edit, store, and retrieve spatial data with relative ease. This project addressed the development of workflows to exploit the import/export, storage and editing functions of GIS to eliminate inconsistent production and reproduction of MEP MIO data.

ESRI's PLTS Nautical Solution extension has made it easier to manage standard ENC and other data used for nautical/navigational products in S-57 format. This extension and ESRI's core software manages storage, importing/exporting data in S-57 format, and workflows for consistently creating and editing ENC data. This project addressed four issues surrounding the extension of the PLTS Nautical Solution capabilities for dealing with MEP MIOs: data model/database extension, import/export capability modification, PLTS knowledgebase configurations, and workflow development.

1.3.1. Database Problem

The first problem this project sought to resolve was the extension of the ENC data model and database. The current ENC data model and database needed to be expanded to incorporate the features and attributes identified in the preliminary specification sheet for MEP MIOs that was extended for marine conservation users for this project. This includes the addition of point, line, and polygon coral reef and MPA subtypes to the appropriate feature classes. Two additional polygon features were also added to represent buffer zones around the new coral reef and MPA features for decision support. Addition of attributes to the appropriate abstract class, coded value and range domains also needed to be created and applied to the appropriate fields.

MIO geometry must coincide properly with ENC geometry to be effectively used on Electronic Chart Display and Information Systems. This lead to the need for determining relationships between ENC and MIO features to ensure object coincidence. Topological relationships were defined and implemented; matching projections were also used also to ensure coincidence. These relationships were developed between existing ENC cell data and MIO data to ensure integrity and proper overlay.

1.3.2. Data Interoperability Problem

The second problem this project sought to resolve was the extension of the import/export capabilities of PLTS Nautical Solution. The current XML schema mapping file is not sufficient or designed to import or export MIO data. This file needed to be configured to import and export the features that comprise MEP MIOs: coral reefs and Marine Protected Areas. The Nautical Solutions import/export engine also needed to be configured.

1.3.3. Editing Constraint Problem

The third problem this project sought to resolve was the extension of the PLTS knowledgebase and workflow development for MEP MIO creation. The knowledgebase configurations indemnify MEP MIO data from invalid data entry while providing a means for on-the-fly attribute and attribute combination validation. Configurations to the existing Master Control tables, Field Filter tables, and Error tables helped resolve consistent data production problems. Workflows for implementing these configurations and creating MEP MIOs needed to be developed and documented as well.

In short, to solve the problem of consistent MIO production, several things needed to take place. An specification sheet needed to be developed first. This specification sheet would then feed the configuration of ESRI's PLTS Nautical Solution. The configurations were made on three fronts: data model and database extension, import/export schema file and engine, and central knowledgebase configurations. These configurations allowed for consistent production and reproduction of MEP MIOs.

1.4. Project Goals

This section documents the goals this project accomplished allowed for consistent MEP MIO creation and maintenance using ESRI software.

The main goal of this project was to consistently produce and reproduce MEP MIO data and MIOs S-57 format. In order to do so, several minor goals needed to be met. These goals correspond to the deliverables and functional requirements that are identified in Chapter 3.

1.4.1. MIO: Consistency through Standards

The major goal of this project was to create an ArcGIS computer environment conducive to consistent creation of Marine Environmental Protection Marine Information Overlay data and MIO in S-57 format. This data must adhere to specific standards, so a product specification sheet was needed to ensure consistency. A draft version of an MEP encoding guide has been submitted to the Committee on Hydrographic Requirements for Information Systems (CHRIS) for consideration. This guide outlines objects and attributes for use in MEP MIOs. To retrofit these for marine conservationists and a higher level of navigational awareness, auxiliary objects and attributes needed to be added to the draft encoding guide. Identifying and compiling these additional objects and attributes with the draft encoding guide was the first part of the consistent creation goal of this project. These standard specifications for MEP data will enable marine conservationists to share datasets and visualize data in situ with ENC aboard ships. The specifications will also provide mariners with an enhanced level of consistent information for navigational awareness.

The second part of this goal was to incorporate and implement the encoding guide into the PLTS Nautical Solution. The specifications were used as a guide to configure the product knowledgebase that manages constraints on valid attribute values and MEP objects allowed into the database.

Together, these two aspects allowed for consistent creation of coral reef and marine protected area data for use in MEP MIO.

1.4.2. MIO: Inclusion into the Database

The second goal of this project was to extend the current database model used for ENC creation to include the objects and attributes in the MEP encoding guide. This was essential to provide a means of ENC and MEP MIO data communication, important to ensure proper data coincidence. Proper MIO overlay onto ENC is essential for providing seamless data integration for display on ECDIS. Failure of coincidence can hinder visual analysis and cause ECDIS errors, resulting in possible damage to ships or the environment.

1.4.3. MIO: Constrained Editing for Data Overlay Consistency

The third goal of this project was to ensure that when instantiating or editing the new features in the database they would be as consistent as possible. Consistency in attribution, geometry, and coincidence was the goal that would lead to consistent MEP MIO upon export. The encoding mentioned in section 2.1.1 aided in this effort. To fulfill this goal, modifications to the PLTS Nautical Solution ENC knowledgebase were completed to create a MIO-ENC knowledgebase. The knowledgebase managed attribution edits. These configurations were critical to ensure consistency during MIO production and reproduction.

1.4.4. MIO: Importing and Exporting

The fourth goal of this project was to produce MEP MIOs in S-57 format in order to show proof of concept for project and software feasibility. This goal focused on extending the existing XML product files to create a MIO-specific and enhanced ENC cell.

1.5. Audience

The remainder of this document is intended for hydrographic data producers, specifically parties involved with ENC data production looking to extend their business model to support MIO creation. Individuals interested in information overlay and data interoperability can also find useful information in this project report.

1.6. Results

This project sought to create an ArcGIS computer environment conducive to consistent production and reproduction of Marine Environmental Protection MIOs in S-57 format. To create this environment, ArcGIS PLTS Nautical Solution was configured to perform the necessary functions to constrain attribution and ensure geometric coincidence. Additionally, database customization occurred to provide a storage container for MEP data, and conceptual workflows for MIO creation were developed.

Modifications were made to XML documents that control object and attribute mapping. This allowed for importation of data into the database but failed to support export. Diagnostic testing and consultation confirmed that this was the effect of malfunctioning software; repairs to it were outside the projects scope.

A new database model was created that allowed for storage of ENC and MIO data together. This database allowed MIO and ENC data to communicate and ensure coincidence of geometric representations through ArcGIS functionality. To ensure proper data coincidence topological rules were created and implemented through ArcGIS.

To constrain attribution of features, the ENC knowledgebase was configured. This consisted of modification to several of the tables in the existing knowledgebase that created a new knowledgebase applicable to MEP MIOs. Attribution constriction worked properly for all point and line features. For the polygon features of both coral reef and marine protected areas the conditions for attribute control did not work properly during on-the-fly validation, but they worked well during PLTS Data Reviewer validation. This incongruity is the result of errors in the PLTS application code that have been verified by the client.

1.7. Organization of the Rest of this Paper

The remainder of this paper is structured as follows. Chapter 2 takes a look at the background of this project and reviews relevant literature on specific pieces of the project. Chapter 3 begins with project requirement documentation, then moves into a description of the system, project plan, and deliverables, and technical execution. Chapter 3 concludes with a post hoc analysis of the project plan. Chapter 4 documents the database design. Chapter 5 describes the approach and strides made to complete this project—that is the implementation. Chapter 6 illustrates the results of the project, system execution, and implementation. Chapter 7 closes this report with conclusions and recommendations for further work. This final chapter is followed by references and appendices.

2. Background and Literature Review

This section introduces the reader to several concepts useful for orientating one's self for meaningful assessment of this project. Section 2.1 develops a base understanding of the S-57 standard as they are today and the move to extend this standard to additional marine information, MIOs. This section goes on to document the use of GIS for management of this standardized data as well as one particular solution developed by ESRI. Section 2.2 reviews relevant literature and previous work to this project. The concepts reviewed in this section are the foundation of the modifications and extensions made to create an ArcGIS computer environment conducive to consistent production of MIO data and MIOs.

2.1. Background

2.1.1. Hydrographic Data Standards

The S-57 format and standard (called The Standard for the remainder of this paper) is the standard developed by the International Hydrographic Organization, IHO, for digital hydrographic data exchange, which the ENC uses (Figurer 1). This standard, which outlines the format for hydrographic data dissemination and transfer, was created in 1992 and has undergone several changes and editions. Edition 3.0 was created and frozen in 1996 to smooth the progress of ENC production and to provide stability to ECDIS manufacturers. The Standard ensures that hydrographic data conform to specific content, display, and representation guidelines (International Hydrographic Organization, 2000). It also allows for ENC cells and other hydrographic data to be utilized by different consumers on different ECDISs.

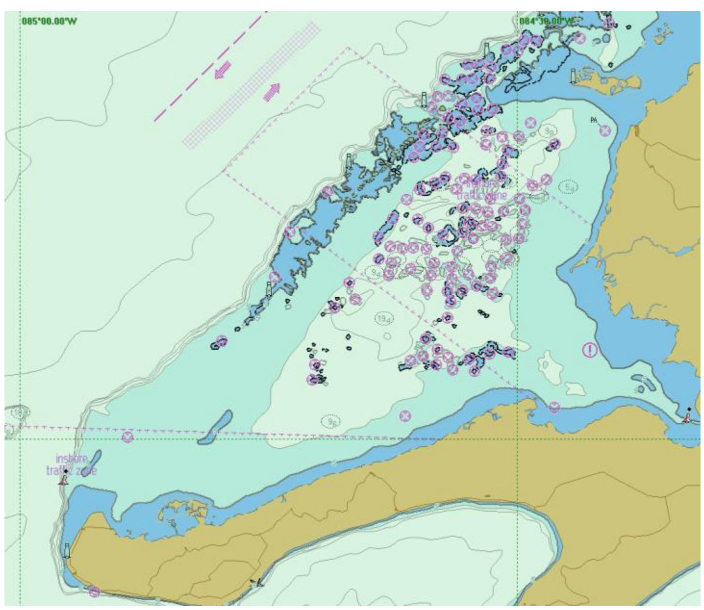

Figure 1. Example of an ENC Cell

The Standard also specifies the object and attribute catalog that outlines and describes permissible hydrographic features and their attributes for use in hydrographic data. The attribute catalog also specifies acceptable values, value ranges, value domains, and data types for each objects attributes. Any addition to either of these catalogs must be carefully considered for its merit by the IHO. Because adding information to already complex charts may confuse the user. New S-57 features and their attributes must have these types of data specifications documented to maintain consistency for storage, production, and representation. Additional objects and attributes need to be registered with the IHO Feature Data Dictionary Registry. Once submitted, further examination by the IHO must take place before objects and attributes are permanently added to The Standard and integrated into the object and attribute catalog.

The Standard allows three geometric primitives: nodes, edges, and faces. These translate into ArcGIS geometries as points, lines, and polygons. Because these three types of geometries are comparable, ESRI products can be used as an acceptable system for storage and maintenance of this data. The Standard and ENC specifications also dictate topological consistency of the data. The standard specifies chain node topology to maintain geometric consistency and coincidence. ESRI products are able to integrate topological rules for geometric constraint which, again, makes it a suitable data management and maintenance system.

2.1.2. Adding Information to the Standard

There is an ongoing discussion in the international community (including IHO, CHRIS, IMO, and various subcommittees) regarding the inclusion of supplementary marine information for use by diverse user groups. This information will be overlaid on top of ENC cells and displayed on ECDISs by mariners, conservationists, and other users. This supplemental information can assist in many different tasks, including safe navigation, resource discovery, and conservation. A major advantage for the inclusion of these data overlays is the potential to improve management and use of marine resources. This provides other ENC users (e.g. major ocean going vessels) with additional in-depth information about features in their vicinity. The following MIO categories have been developed and identified as being useful across multiple domains (Harmonization Group on Marine Information Overlays, 2007):

- Aids-to-navigation (AtoN)
- Current flow
- Sailing Directions
- Ice coverage
- Logistics
- Marine environmental protection
    - -Coral Reef and Marine Protected Area (MPA)
- Oceanographic
- Pipelines/cables
- Rivers/Inland Waterways
- Security
- Tide/water level
- Viewpoint
- Weather/meteorological

Each of these categories represents a new set of features and information that can be used in conjunction with ENC aboard ships. As with the ENC data, MIO features must also adhere to The Standard. Many of the representational and data format parameters (e.g., geometry, languages used, and projection) are identical to ENC; most of the development for MIOs involves feature and attribute definitions. The Homogenization Group on Marine Information Overlays (HGMIO), NOAA, and CHRIS are engaged in preliminary work to create a specification sheet for Marine Environmental Protection (MEP) MIOs. A proposal and draft encoding guide was submitted by NOAA at the 19th annual CHRIS meeting in November, 2007. This draft encoding guide outlined features, attributes, and attributes values for coral reefs and Marine Protected Area features. These MIO encoding guides are intended to be dynamic documents, adaptable to specific user and product needs. Building onto the standard specifications allows consistent domain-specific Marine Environmental Protection (MEP) MIOs to be produced.

2.1.3. Managing S-57 Data

Many different strategies are available to store and maintain geographic data. The S-57 format defines the data model and data structure for dissemination and transfer of digital hydrographic data (e.g., ENC). Considerations for storage and maintenance of data used to create an ENC are outside the scope of its governing body and are not specified. This fact has opened the door for software companies to produce diverse data management solutions for ENC production.

ESRI has developed an extension to its standard geographic information system, ArcGIS, to provide solution-consistent data production. This extension, ArcGIS PLTS, was created specifically to streamline data production and provide a computer environment that assists in consistent data production and reproduction. ESRI has further extended PLTS for domain-specific data solutions including topographic, military, aeronautical, and nautical domains. PLTS Nautical Solution is designed to assist and streamline the maintenance and production of several different digital and hard-copy nautical chart products including ENCs.

2.1.4. Creating and Storing S-57 Datasets

One aspect of PLTS Nautical Solution is the ENC database template. This database template is designed to store S-57 objects used for ENC production. Designed and built using the international ENC encoding guide and S-57 specifications, the database template provides an S-57-compatible container for objects and their attributes used on an ENC. By leveraging the Field Filter and Master Condition tables, the PLTS Nautical Solution and the ENC database schema constrain editing while guiding data maintenance through pick lists and domains. This provides an environment for consistent ENC production and reproduction. The ENC database, software, and PLTS extension were modified to include additional MIO features, using object and attribute catalogs and specification sheets. Additional modifications to the import/export engine and product XML files (used for object and attribute mapping and data interoperability) would yield the ability to create consistent and standardized MIOs for consumption by users of shipboard navigation systems such as ECDIS, as well as other users.

2.2. Literature Review

2.2.1. The Move from Paper Charts to Digital ENC

It is important for mariners and marine conservationists to understand the environment in which they work in order to achieve a greater level of safety in navigation and effective resource management. Widespread mapping efforts have provided these two user groups with up-to-date information on oceanic resources and navigational aids. Historically this has existed in the form of paper charts. Because of the static nature of hard-copy charts and the inherently slow mechanical process of updating them they are unsuitable for displaying additional types of information that would be useful for more applications in the marine environment. Paper charts also have limited capabilities of representation, and a definite low temporal resolution in comparison with the dynamic marine environment. Using computers and Electronic Chart Display and Information Systems can decrease the time it takes to create and utilize marine information.

Computers have the capability for consistent data creation, updating, and dynamic modeling for monitoring resource use, management, and navigation of the ocean environment. As observed by Tetly (1986) "Over the past few years electronics has moved into a sphere of charting and now digital chart data is becoming more popular and is likely to become the mainstay product of the hydrographic offices in the years to come". Electronic chart display and information systems have become a widely used means for navigation at sea. An ECDIS uses Electronic Navigational Charts (ENC) to display navigational information for use by navigators on large vessels. An ENC is "the database [of marine information and phenomenon], standardized as to content, structure, and format, issued for use with ECDIS on the authority of government-authorized hydrographic offices" (HGMIO, 2007). ENC cells are also the end product produced from the database. ECDIS and ENC are being utilized in various fields to support many new applications along side of navigation. Therefore, this medium for data display can and should be extended to enable to user to visualize and analyze other marine information.

2.2.2. Standards for Marine Information Overlays

In order to provide consistent representation of navigation and marine features in the ENC database and other hydrographic data, the IHO adopted the S-57 standard (IHO, 1992), which dictates the transfer and dissemination of "digital hydrographic data between national hydrographic offices and for its distribution to manufacturers [of ECDIS], mariners, and other data users" (IHO, 2003). The standardized ENC database has focused mainly on information for navigation, negating ecological and temporally sensitive data that can have uses in navigation as well as multiple arenas. This has led to the creation of Marine Information Overlays (MIO).

MIOs are considered to be auxiliary information to be used with an Electronic Chart Display and Information System which are not Electronic Navigational Charts features/objects or specified navigational elements or parameters (HGMIO, 2007). The Harmonization Group on Marine Information Overlays continues to work on MIO specifications and has identified several areas of MIO development for further research into modeling and representation; these are listed in section 1.1.2. The creation and use of one type of MIO, Marine Environmental Protection, allows for enhanced shipboard use of marine data for research, conservation, resource management, and planning as well as increased navigational efficiency and safety. This improvement is accomplished through a more accurate representation and display of coral reefs and Marine Protected Areas.

However, with the ability to easily create and manage vast amounts of marine data with geographic information systems, it becomes likelier to confuse and overload the user with too much information. This can have negative financial, human, and environmental consequences. Alexander (2005) comments that "Maritime accidents, as well as routine ship operations … can cause significant loss or injury to coral reefs, resulting in habitat damage that adversely impacts the tourism industry and the communities that depend on coral reef sustainability for their livelihoods". Damages caused by unclear representation of marine data can result in real harm to the environment as well as the imposition of fines and the loss of cargo, the value of which can reach into the millions of dollars. Raw numbers of fiscal loss do not account for the immeasurable value of human life that has been and can be lost. These issues can be mitigated through the use of appropriate clear symbology and consistent representation of important oceanic phenomenon in accordance with S-57 specifications.

Extending The Standard to incorporate MEP data allows for more accurate environmental protection, environmental monitoring, and other public and private endeavors. These are accomplished through identification and visualization of resources in the same medium as the navigation information, i.e., S-57 formatted ENC cells. When incorporating MIO data with existing ENC navigation data on ECDIS, there need to be specific guidelines to ensure the usefulness, consistence, and coincidence of the data (Alexander, 2008). Compiling these guidelines into a specification sheet similar in layout and format to the S-57 object and attribute encoding guide is part of the work being done by the HGMIO and the Committee on Hydrographic Requirements for Information Systems. A draft product specification of MEP objects (coral reef and marine protected areas) and attributes has been submitted for review to CHRIS (National Oceanic and Atmospheric Administration, 2007). Since MIOs are considered to be auxiliary information, there are few limits to the objects and attributes that can be used to comprise them. Any S-57 object or attribute can be used for MIOs as well as ones specifically created to fulfill new requirements or applications (Homogenization Group on Marine Information Overlays, 2007). These additional objects and attributes need to be registered with the IHO Feature Data Dictionary Registry for use. This opens the door for development of a number of application or domain-specific MIOs for many uses. Adding objects and attributes for data overlay with ENC cells begs the question of how to manage and consistently produce these overlays alongside the ENC data to ensure coincidence.

2.2.3. The Role of GIS in ENC and MIO creation

GIS technology makes the compilation, maintenance, and management of geographic data more efficient, the result of ease of storage and retrieval of digital data and computerized creation and editing. This being the case, there has been a plethora of marine information created for many reasons, ranging from navigation to scientific exploration and natural resource location and identification (Write, 2002). This medium for creating and storing marine data has been and should continue to be harnessed for use in the creation of MIO.

Those who use GIS for the creation and management of critical and auxiliary marine features must proceed with caution. This is necessary to ensure the integrity of, consistency with, and adherence to the international standards for navigation, conservation, and decision-support information. The Standard allows GIS to fill this need and allow MIO data to be accessed by ECDIS for navigation planning to prevent the loss of human life and damage to cargo.

2.2.4. XML and Data Interoperability

GIS is a helpful tool for creating and managing the spatial data that make up MIO and ENC. Transferring data between GIS and ECDIS is an issue that needs attention. Due to structure, format, and other reasons (e.g., shared geometry, binary format and size specifications) S-57 formatted data is not directly readable in most off-the-shelf GIS packages. A controlled conversion between the S-57 format and other standard GIS formatted data is needed. As Kieran Millard (2005) stated "The need for a common data framework to enable this [conversion between S-57 and other standard GIS formats] integration has now become an essential component of building our knowledge of the marine environment". Millard and his colleagues (2005) assert that using XML standard has great possibility to develop this framework.

XML is employed in Web applications, Web design, and data display definition. The overarching theme of all XML documents is that XML is intended to be used as a means to store and exchange data. The power of using XML is twofold: XML documents are mostly human-readable and are domain specific. Human-readable documents by way of the element type tags (or tags, as they are commonly called) are self describing. This means that each part of the XML document is named in a way meaningful for its application. For example, the body of an e-mail message is stored between the body element opening tag, <body>, and the body element closing tag, </body>. Also XML documents are domain specific. This means that the tags are developed for specific applications or uses. Using the example from above, the body tags <body> and </body> are used for transferring the body of an e-mail message. In transferring information in a different document, the body tag could represent another element of the data, such as the governing body of a natural preserve, or the greater body of water smaller ones make up in a multi-patch feature. These tags are consistent with the vocabulary used within the domain. The tag definitions are defined in the XML parser and allow the XML document to be deconstructed into its constituent parts. These parts are then used to rebuild the data in different formats or applications (Watt, 2002).

XML can be used to define data schema at a level that is understood by both humans and computers. XML's software and technology independence allows for data to be transferable between systems. Using XML, it is easier to match data schemas and understand data semantics due to the use of the domain specific, user defined, and self describing tags. These tags allow for identification of similarities between different data sets through the use of ontology and semantic or straight forward attribute mapping. Identification of semantic similarities between features and their attributes can be used to define and map the connections between datasets in different formats and structures. The similarity maps (XML documents) can be used to guide information within a single dataset in a single format to another dataset in a different format. The use of semantic mapping and XML for data interoperability was demonstrated by Villie Morocho, et al.(2004) Morocho approaches the data interchange problem a different way than others. By creating schema maps of semantic similarities and differences between databases a connection is made between datasets and formats. This allows information to be brought together from different formats into a common system. XML and XMI (XML Metadata Interchange) were used in order to provide a common schema description that allows this connection between data to be made and data to be interchanged between file formats.

XML is being used in many applications. ESRI has extended their products to export data to XML files and allows for the import of some XML files directly. A major use of XML within ESRI products is utilizing it for database schema transfer. This allows databases and database templates to be produced and shared. Shared database schemas and templates create a standardized representation of features for consumption and storage of spatial data (including ENC and MIO data). By using XML to define database schema and data structure, migration of different data formats into a geodatabase for storage and maintenance becomes more efficient and effective.

2.2.5. Smart Storage and Consistent Creation

A core component of GIS is the storage of spatial data. Using the ESRI structure and geodatabase model has a significant amount of strength when it comes to the storage of spatial data. For the storage of MIO data, this strength is namely the definition of topological relationships and relationship classes. These relationships can be extended further by use of object-oriented UML modeling to define specific behaviors between the separate MIO data and the ENC database to ensure coincidence and accuracy.

GIS strength for the maintenance of MIO data lies in its controlled editing environment and in the use of topology to maintain geometric consistency. A controlled editing environment allows for consistent production, representation, and attribution of MIO data in accordance with its specification sheet and The Standard. ESRI software can implement twenty-seven different topology rules to maintain shared geometry. These rules, like the editing environment, assist in consistent production and representation of MIO data. These rules also help maintain coincidence between MIO and ENC objects. For a thorough review of topology, see work from Dr. Max J. Egenhofer and for an ArcGIS user perspective review see the ESRI help website.

Using GIS Millett and Evans (2001, 2003) highlight the advantages nature of using geodatabases for marine and hydrographic data storage and maintenance. Most notably the authors cite the geodatabase’s abilities to manage topological relationships and sustain control over editing as discussed above. Both of these abilities are core to maintaining the integrity of MIO data for export to its native format, preserving adherence to standards, and attaining proper overlay onto existing ENC data. The use of the ESRI object-oriented data model (geodatabase) allows objects to become more intelligent with the definition of real-world behaviors that have great implications for marine applications (Wright, et al, 2006). It must be noted that all of the authors mentioned in this section are affiliated with ESRI in one way or another. No work was found discussing the short comings and problems with using of the ESRI geodatabase.

2.3. Summary

The Standard maintains a consistent method for storing and exchanging hydrographic data such as MIO and ENC. These standards dictate how products like ENC cells and MIO look, perform, and represent hydrographic features. In order to provide additional data for marine conservationists and mariners that do not interfere with core navigation data, Marine Information Overlays are being developed. The product specifications that arise from MIO development can be used for guidance on consistent creation using GIS software.

GIS software has much strength for managing and maintaining ENC and MIO data. The use of XML for data interoperability and ESRI software extensions has made the consistent ENC data and cell creation more efficient and effective. Using this work as a basis, configuration of the software for consistent MIO creation is reachable and valuable.

3. Approach to Project: Requirements, System, and Project Plan

This chapter deals with the precursory planning and design that supported the physical work and modifications to equip PLTS Nautical Solution with the capabilities to consistently create MEP MIOs. Section 3.1 documents the project requirements. Section 3.2 documents the overarching system concept, design, the architecture used to complete the project, and briefly touches on the database design. Section 3.3 documents the project plan formulated for its completion as well as its deliverables. Section 3.4 documents the technology and the technical approach taken to complete the project. Section 3.5 concludes this chapter with a post hoc analysis of the project plan.

3.1. Requirements

Initial work for project panning focused on defining the requirements for the project. This was done through several meeting with the client and advisors. Additional research on navigation and standards led to the formation of the requirement elaborated on in the following paragraphs. These requirements are important to orient the reader and give them the tools to objectively measure the validity of this projects methods and measure its success

This project had three areas of functional requirements: import/export; data storage; and data creation and management. The list below identifies nine system functional requirements this project was to fulfill.

1. The system must import S-57 formatted data
2. The system must export MEP data to S-57 formatted ENC cells and S-57 formatted MIOs
3. The system must instantiate proper MEP and ENC features from S-57 data during import
4. The system's import and export must utilize XML for schema definition and translation
5. The system's database must hold additional MIO data and allow interaction with ENC data
6. The system must allow for the storage of MEP MIO features as points, lines and polygons features
7. The system must validate attributes specified in the draft encoding guide and central knowledgebase for consistency constraints
8. The system must implement topology between MEP MIO data and ENC data within the geodatabase for geometric validation, where applicable
9. The system must provide a venue for editing and updating MIO data

The functionality for all these requirements was previously available in PLTS Nautical Solution for ENC and other nautical products. Extending the functional capabilities of PLTS to cover MEP MIO objects so they would meet the same requirements was the goal of this project.

3.2. System

The goals of this project were to apply consistency to MIO data through extending and implementing standards, create a database to store the data, constrain editing of the data during maintenance, and modify import/export files so MIOs could be created or imported into the database. This was archived by extending the current PLTS ENC production system to be viable for MEP MIOs. Much of the existing PLTS Nautical Solution system was leveraged to complete the project. The system is composed of three parts: PLTS Nautical Solution, ArcGIS, and MEP encoding guide. Conceptually, the system works as described below:

S-57 and other nautical data are imported into the ENC-MIO geodatabase template. The geodatabase template is based on the existing ENC data model and the MEP encoding guide. S-57 formatted data is imported into the database using the PLTS import\export engine (Figure 2). This makes use of XML files to map between the schemas of the S-57 data and geodatabase objects. The XML files define how the geometric and attribute information in S-57 cells match that of the features classes and subtypes in the geodatabases, and the import/export engine populates the individual records in the database. Data in other formats is integrated through various ArcMap tools.

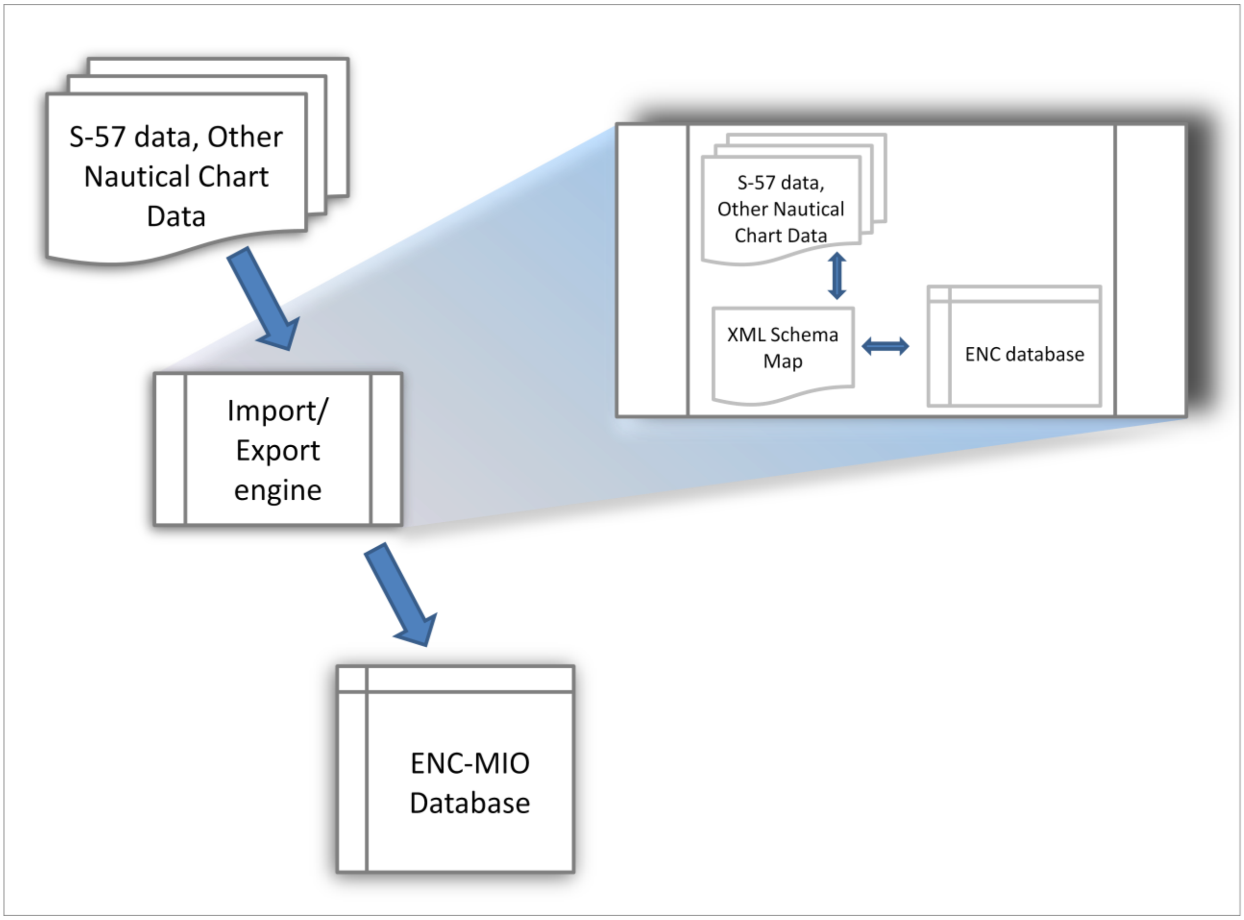

Figure 2. Data Import

With the data stored in the geodatabase, the PLTS Nautical Solution MIO-ENC knowledgebase and ArcGIS help to maintain data consistency during production. This is done through a series of related tables in the knowledgebase linked behind the scenes in the PLTS application. These tables control and validate attribute values and attribute combinations through *where* clauses. (Additional functionality of the knowledgebase deals with cartographic representation and other data representation aspects but is not part of this project.) Generally, the knowledgebase is utilized behind the scenes by PLTS. The PLTS application looks up the name of the feature class and subtype being edited in the Database Feature Class Valid Value table (DBS_FC_VVT table). This table contains the validation ID number (VALIDATIONOID attribute) that links the feature class to the Master Condition table (PLTS_MASTER_CNT table). The Master Condition table contains *where* clauses using SQL syntax to check and validate attributes. These conditions are based on the MEP encoding guide and functional relationships between attributes. This table contains an error number that links to the Error table (PLTS_ERRORS table). This table contains the real-world explanations of the errors that were encountered during validation. When the user applies on-the-fly validation to attributes, PLTS uses these tables to check feature attribution and flag errors in attribution to maintain consistency. Core ArcGIS attribute validation is also executed in this process to constrain attribute values.

Topologic rules are implemented between features for geometric consistency and proper overlay. These rules are validated using core ArcGIS topology validation tools. Once data has been created and validated, the import/export engine uses the same XML files to map connections between the data formats and export the data into S-57 formatted ENC cells or MIO. This data can also be used for hardcopy chart production. The system concept is visualized in Figure 3.

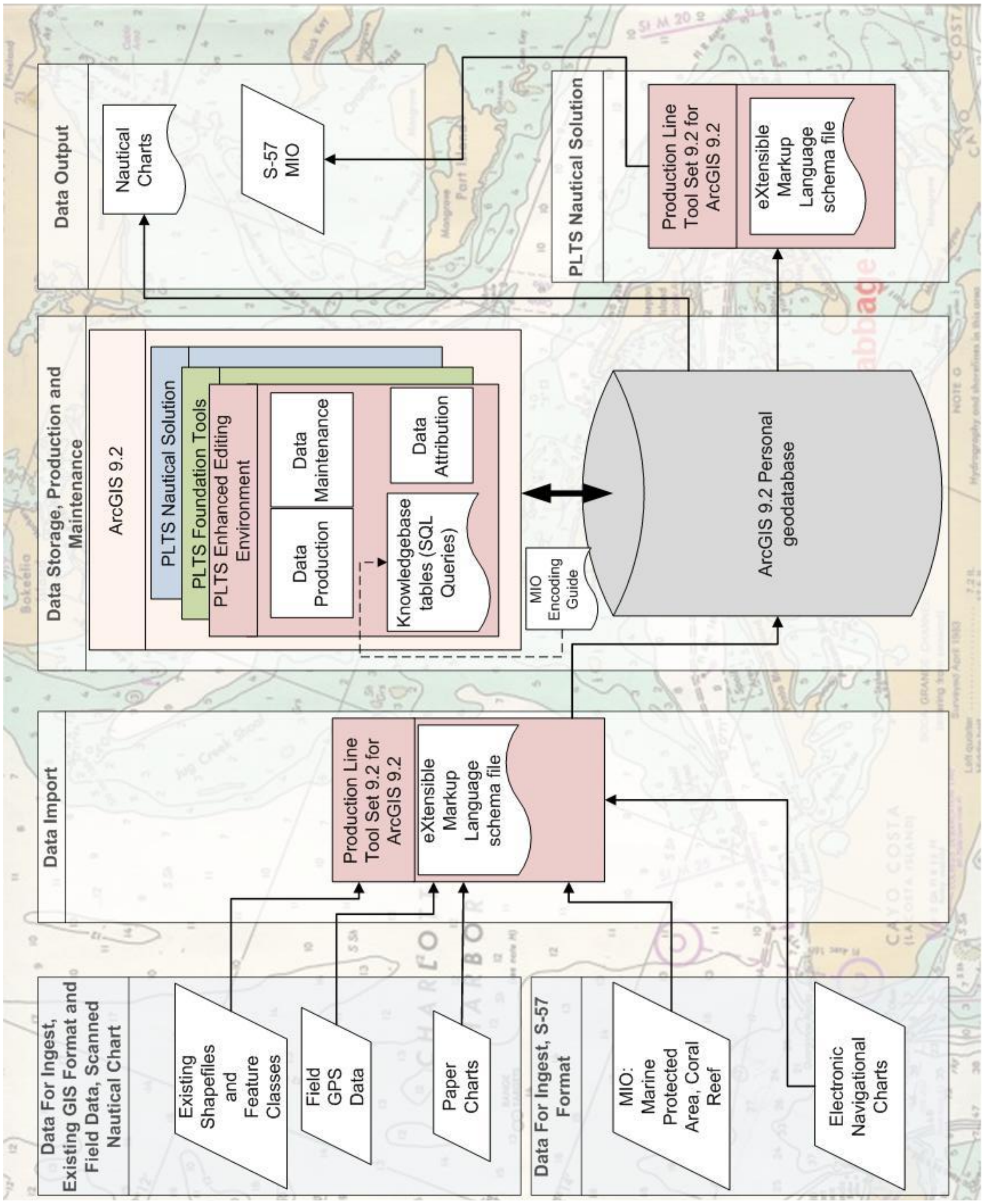

Figure 3. Visual System Concept and System Architecture

When the system was implemented, it had the intended purpose of fulfilling the use case outlined below:

1. The user needs to create a Marine Environmental Protection MIO.
2. The user obtains a current ENC cell for the area of interest.
3. The user instantiates the MIO-ENC database with ENC cell data using S-57 importer in PLTS.
4. The user identifies the objects that currently represent coral reefs or MPAs in the database.
5. The user identifies and acquires additional data for coral reefs and MPAs and incorporates it into an ArcMap session. This data could be existing GIS data, data collected in the field, or scanned and georeferenced nautical charts.
6. The user creates features of interest in the new coral reef and MPA subtypes during an edit session.
7. The user attributes the features and validates them using on-the-fly validation.
8. Attribute and geometry errors are returned that identify incorrect or illogical attribute values or combinations as well as incorrect coincidence of features.
9. The user corrects the feature attributes and geometry then revalidates.
10. If no errors are encountered, the user accepts the changes and saves the edits.
11. The user exports MEP MIO data into S-57 format, specifying the correct product XML file.

Figure 4 shows how users interact with the system.

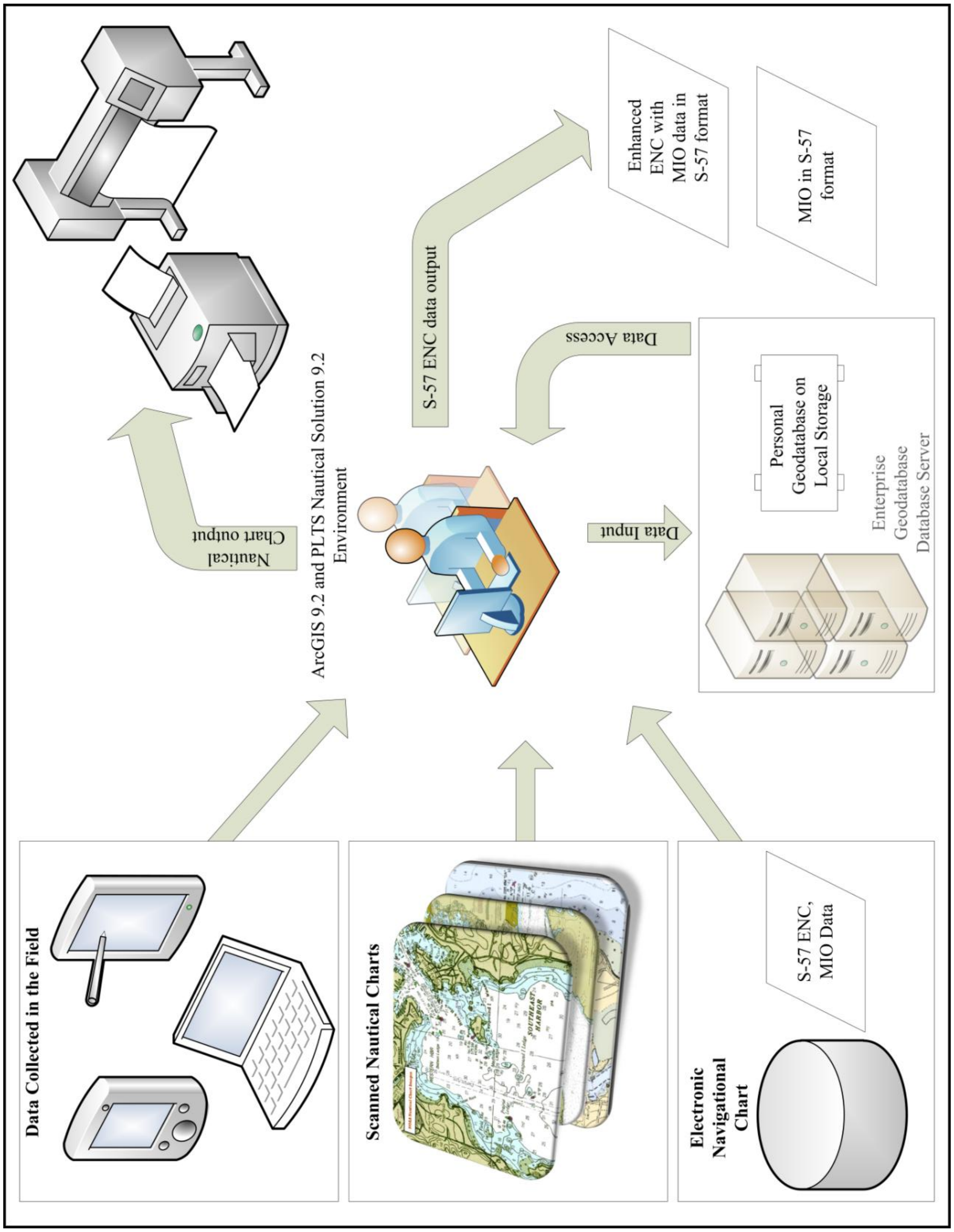

Figure 4. User Interaction with the System

3.2.1. System Design and Architecture

In order to best meet the goals outlined for the project and add the most value for the client in the time allotted, the system's software architecture was uniquely constructed. The database extensions would be completed leveraging the 9.3 version of the ENC database model. This is the version for use with ArcGIS and PLTS Nautical Solution 9.3. The knowledgebase and XML schema configurations were also done on the 9.3 versions of these components. With resource constraints, these components were implemented using the 9.2 version ArcGIS and PLTS Nautical Solution.

The project system required the basic needs for hardware set by ESRI for Arc Desktop 9.2 and PLTS Nautical Solution: 1.6 GHz recommended or higher CPU; 1 GB minimum RAM; 1.2 GB disk space; DVD-ROM drive; 256 color depth with 1024 x 768 screen resolution; 500 MB minimum SWAP space. The project was implemented using a Dell Precision M4300 laptop with 3GB RAM and 120-GB hard disk space. This computer linked to a server running Microsoft Windows Server 2003 R2 enterprise edition through a remote desktop connection. This server had adequate specifications to run the required software. The remote connection to a server was necessary due to the unique ArcGIS and PLTS Nautical Solution software configurations. For PLTS Nautical Solution and PLTS Foundation Tools to work properly within ArcGIS, the software needed service packs 1, 2, and 3, respectively.

3.2.2. Database Design

The database design used for this project was a configured geodatabase. A personal geodatabase paradigm was chosen for storage of Marine Environmental Protection Marine Information Overlays. This design allowed for extended access to database tables compared to the file geodatabase option. The database design and implementation is discussed thoroughly in Chapter 4.

3.3. Project Plan, and Deliverables

This section discusses three aspects of project planning undertaken to ensure thorough completion of the project. The first aspect is the project execution plan, which broke down the project into three stages: design, creation, and implementation and testing. Next was the project schedule that outlined the time table for project completion and third is the project risks and mitigation strategies that were put into place to reduce their impact.

3.3.1. Project Plan

This project was broken into three phases: design, creation, and implementation and testing. After the three phases are documented, the project schedule is discussed and a Gantt chart is provided for visual reference. Risks identified at the beginning of the project are enumerated in section 3.3.5 and the total risk level is calculated. These plans and risks are reevaluated in the ad hoc plan analysis section of this chapter.

3.3.2. Design Phase

The first phase of the project focused on the design of a MEP MIO encoding guide. This consisted of identifying coral reef and MPA objects and attributes that were of value to marine conservationists and mariners. An analysis of marine conservation case studies and conservation manuals and handbooks yielded 17 additional attributes and two additional objects to be included in the draft specification sheet. These objects and attributes, along with the existing draft specification sheet, were compiled into a new document. This extended draft specification sheet made up of the object and attribute catalogs was used in the second phase to guide database creation and PLTS modifications. Samples of these two documents are shown in Figures 6 and 7. Full copies of these documents are available in Appendices A.1 and A.2.

Designing and creating the specification sheet served two purposes: (1) it would extend the draft specification sheet to better represent MEP features in general and specifically for marine conservationists and (2) it would act as a guide for database modeling. In this way, the specification sheet also served as the conceptual model/design for the coral and MPA objects database.

3.3.3. Creation Phase

The second phase of this project focused on the creation of objects and attributes conceived in the design phase. This consisted of two parts: (1) database modeling and (2) PLTS knowledgebase configurations.

To better understand the principles and mechanics of UML database modeling, approximately 30 hours of research and training tutorials were completed. This consisted of extensive research on Computer Aided Software Engendering (CASE) tools, UML modeling, and object-oriented design, as well as completion of tutorials and workbooks. Database modeling was done using CASE tools and Microsoft Visio.

This phase was responsible for the creation of the database model and physical database for MEP and ENC data. The new UML database model leveraged existing ENC database model components for creation. During this phase the new model’s schema was used to create the physical database in the form of a geodatabase template. This process is discussed more thoroughly in Chapter 4.

During this phase, modifications were also made to the PLTS Nautical Solution. These consisted of XML import/export file and knowledgebase configurations. The modifications were accomplished using Microsoft Access and a basic XML editor program. This process is discussed more thoroughly in section 5.2.

3.3.4. Testing Phase

This phase was chiefly concerned with putting the components created in Phase 2 into action. It is important to note that creation and implementation are often iterative. During implementation and testing, several changes to the data model and XML files needed to be made as a result of implementation and testing results.

During this phase the products resultant from the creation phase (the database template and knowledgebase) were integrated into the ArcGIS and PLTS software. This step was followed by testing of import/export functionality, edit constraints, and attribute validation. Results and findings from implementation are covered more thoroughly in Chapters 5 and 6.

3.3.5. Schedule

The project was scheduled to last 257 days. The project schedule reflects the project phases mentioned in the previous section. Examination of the schedule reveals dependencies between phases and phase elements. One example is the dependency between finalizing the MEP encoding guide and database design and creation. A second example is the dependency between database creation and testing. Resource constraints required an overlap between phases and development. This hindered development in some areas, but it allowed for more thorough research on complementing project aspects while other aspects were waiting for client validation. The rigorous fostered focused work effort and maintained project track while assisting in project evaluation and monitoring. The schedule is shown in Figure 5.

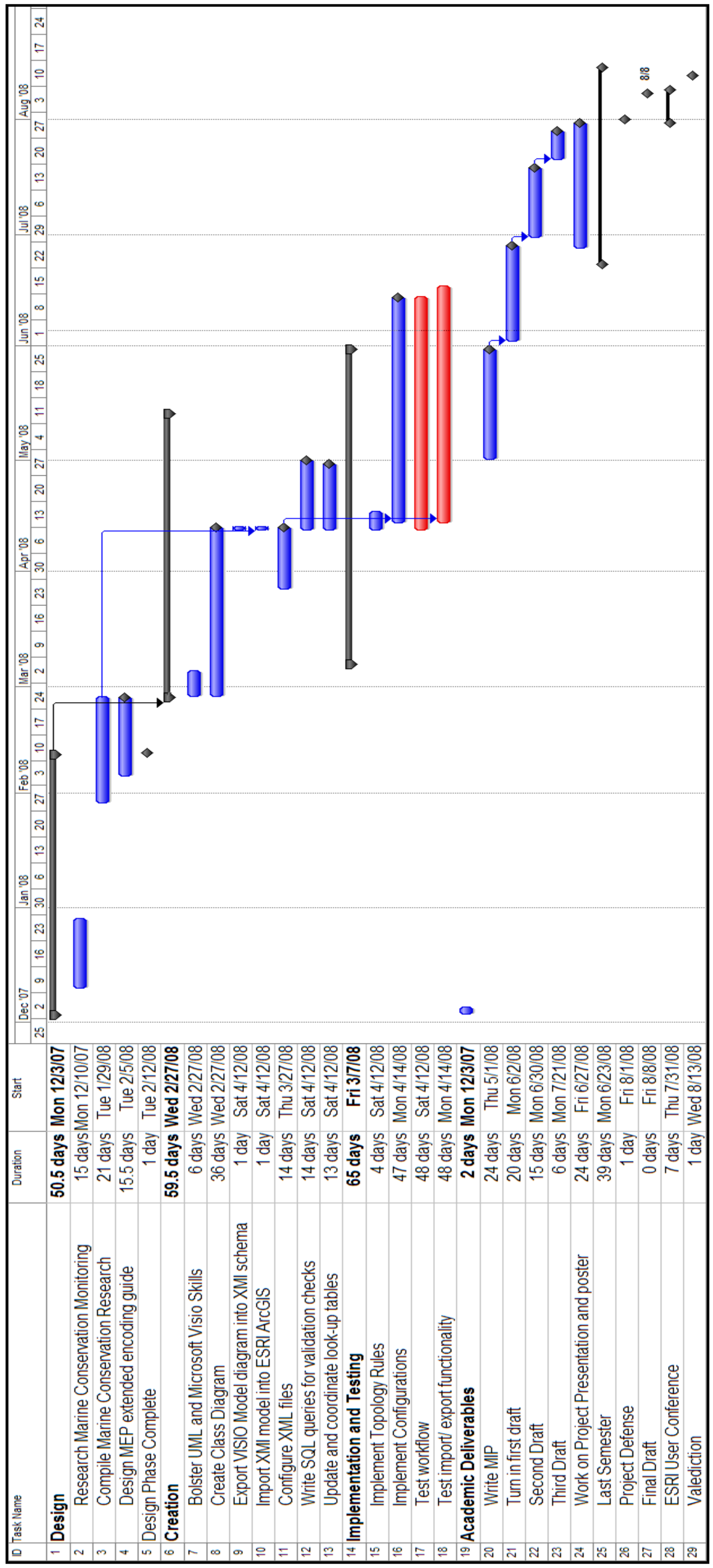

Figure 5. Project Schedule

3.3.6. Risks

Risk identification and mitigation are critical to successful completion of any project. Several risks were identified during project planning and mitigation strategies for these were also developed. Most notable is that of software architecture. Using data models and schema maps designed for the newest, unreleased version of software (to provide the most client value) on older versions of software and the unknown ramifications of doing this presented a main threat for project success. The software configuration was the most significant risk. The remaining risks are enumerated in the list below and threat scores and mitigation strategies defined in table 1.

Risk #1: **Temporal Constraints** – The time span for the project was approximately nine months. With a tight schedule, there was little room for setbacks.

Risk #2: **Scope Creep** – A large issue with any project is the modification to the project after initiation. New functionality requests, new object requests, and so forth could have had devastating effects on any project.

Risk #3: Insufficient or inadequate design – There may be problems is coral reef and MPA UML objects are not sufficiently or correctly designed and do not properly interact with existing ENC data.

Risk #4: Uncontrolled external forces – Extreme course workloads, lack of prompt assistance, and computer malfunctions can result in delays.

Risk #5: **Software architecture** – Using data models and XML schemas designed for ArcGIS PLTS 9.3 and implementing them on ArcGIS PLTS 9.2 could create conflicts.

Risk #6: Lack of client Feedback– If the client does not provide feedback in a timely manner, it may be impossible to make changes and move forward with the project.

The risk scores are calculated out of a possible 25 points. This is determined by multiplying the severity score (1 – 5) by the probability (1 – 5). Individual risk scores were totaled and examined against the largest possible score (highest possible score for each risk multiplied by the total number of risks) to determine the overall risk for the project. Overall, this risk scored a modest 60 out of a possible 150. Table 1 breaks down the risk score and mitigation strategy for each risk.

Table 1. Project Risks

Risk	Severity 1-5 scale, 5 being the highest	Probability 1-5 scale, 5 being the highest	Mitigation	Exposure severity x probability
#1: Temporal constraints	5	3	Rigorous schedule with built-it flexibility	15
#2: Scope Creep	3	2	Well-defined goals and deliverables	6
#3: Insufficient or inadequate design	2	1	Research, technical assistance from tech. advisor, training classes	2
#4: Uncontrolled external forces	3	3	Course work completed as possible with time allotted, identify and prioritize what help is needed, backup computer regularly	9
#5 Software architecture	5	4	Thorough testing to reveal any evidence of software configuration as significant roadblock to project completion	20
#6: Lack of client feedback	4	2	Staying in contact to keep the client involved with a sense of ownership and responsibility	8

3.4. Technology and Approach to Project Execution

This project utilized current technology and design techniques for execution. The critical technology infrastructure for the project, design methodology and testing methodology are expounded upon in this section.

3.4.1. Technology

Several software suites were critical for implementation. Microsoft Office Professional was a key software package used all phases of the project. Microsoft Visio 2003 Professional was used for database modeling at the logical and physical levels. The MEP encoding guide served as the conceptual design for the coral reef and MPA objects in the database model. This was executed and documented using Microsoft Word. For database design, an object-oriented methodology was used to encapsulate features into existing schema and hierarchical structure. For XML schema maps, a freeware XML editor was used. Architag X-Ray XML Editor, an XML editing software, provides on-the-fly validation of well-formed XML documents. This software was used for all XML schema-map creation. Validation and second pass schema maps were created using an ESRI's in-house schema map tools. Modifications to knowledgebase tables for attribute constriction and validation, and error reporting made use of Microsoft Access. This provided a venue for table and row selection and modification.

Testing followed an iterative approach and method. As specific features of the project were completed they were tested to verify acceptance. This iterative approach informed the database model and knowledgebase of necessary modifications through errors in functionality, and changes were made accordingly. Scripted tests were used to insure functionality was appropriately examined. The scripted test is supplied in Table 2. For data maintenance during testing, three file folders were created. These consisted of different databases for different types of testing: import, export, and knowledgebase configurations. Multiple replicas of the database model were used for testing each aspect. Depending on the testing being done, databases were instantiated and manipulated to determine results. This is more thoroughly discussed in Chapter 5 and findings from testing are discussed in Chapter 6.

Table 2. Scripted Test

Step	Action	Anticipated Result	Requirement Trace	Observed Result
1	Right-click ENC feature dataset within ENC MIO geodatabase template and select Import S-57 to Geodatabase	Data from ENC cell and/or coral reef/MPA overlay is loaded into geodatabase	3.1.1, 3.1.4	
2	Check geodatabase to make sure proper feature classes were instantiated	All feature classes and attribute fields are properly instantiated	3.1.3, 3.1.5, 3.1.6	
3	Start ArcMap and add data from geodatabase	Data appears in the data viewer within the application	3.1.10	
4	Create coral reef, features and respective buffers with ENC and ArcGIS editing tools in coral reef subtype in NaturalFeaturesP, NaturalFeaturesA, and NaturalFeaturesL Create MPA, features and respective buffers with ENC and ArcGIS editing tools in MPA subtype in Regulated AreasAndLimitsP, Regulated AreasAndLimitsA, and Regulated AreasAndLimitsL	New features are created within the database	3.1.10	
5	Attribute coral reef and MPA features with improper values and attempt to validate	Attributes are flagged as invalid	3.1.7, 3.1.8	
6	Attribute features with proper values and combinations and validate	Attribute changes are accepted	3.1.7, 3.1.8	

7	Validate geometric correctness of data	Violations to topology rules are flagged	3.1.9	
8	Fix topology errors and validate	Geometry becomes correct	3.1.9	
9	Run Update Primitives tool	Geometric Primitives Updated without error		
10	Use the Export to S-57 tool (Same Location as import tool) to export edited geodatabase to an ENC cell	ENC cell is created with additional data from edit session	3.1.2, 3.1.4	
11	Open ENC viewer and display edited cell	ENC cell appears in viewer with additional features and attribute information	3.1.2, 3.1.4	

3.4.2. Project Execution

This project sought to complete four major tasks: (1) create a database to hold MIO features and allow communication between ENC and MIO data, (2) extend the PLTS knowledgebase to allow it to deal with the new features; (3) create an XML schema map for data interoperability between ENC cells adhering to The Standard and the geodatabase template; and (4) define the macro workflow for MEP MIO creation.

For database creation, new point, line, and area subtypes were added to the appropriate feature classes within the UML ENC data model. Supplemental area subtypes were added to the feature classes to represent buffer areas around the main polygon subtypes. The new coral reef features were added to the NaturalFeaturesA, NaturalFeaturesP, and NaturalFeaturesL feature classes as subtypes. The coral reef buffer subtype was added to the Natural FeaturesA feature class as a subtype as well. The new marine protected area features were added to the RegulatedAreasAndLimitsA, RegulatedAreasAndLimitsP, and RegulatedAreasAndLimitsL feature classes as subtypes. The marine protected area buffer subtype was added to the RegulatedAreasAndLimitsA feature class as a subtype as well. Coded value domains were added to the database and applied to coral reef and MPA specific attributes. This was done to assist in maintaining data consistency. Range domains were also added and applied to attributes where applicable for coral reef attributes. This was completed using Microsoft Visio 2003 Professional.

For PLTS knowledgebase configuration, additional records were inserted into several tables to reflect changes and supplements to the database. These additional records assisted in maintaining data consistency of the new features. The knowledgebase's Field

Filter table was modified to allow only necessary attributes to be shown during editing. Field Filter records were added for each of the coral reef and MPA point line and area feature classes. Entries were included in the Domains table to reflect the additional domains created and implemented in the database. Supplemental entries in the Master Condition table were inserted to assist in data consistency. These entries consisted of platform independent *where* clauses used to constrain attribute values and attribute combinations. This table is also used by PLTS to identify errors and relate to the Error table for message reporting. The Error table was also modified in order to provide a trace for the new attribute conditions errors. To facilitate these changes the personal geodatabase used to hold the knowledgebase tables was modified using Microsoft Access.

XML schema maps were configured for data interoperability (import/export) by adding entries for each new feature and associated attributes new to the database. These entries consisted of object maps that defined the relationship between geodatabase objects and S-57 objects. Moreover, associated attributes for all geodatabase objects were also mapped to S-57 attributes within the object map. This allowed different data formats to be interoperable via schema mapping. To complete this task, Architag X-Ray XML Editor and XML Marker were used to create and validate the XML schema maps.

For the macro workflow, the overarching method for MEP MIO creation was defined. This consisted of defining general steps and guidelines to follow for MEP MIO data creation. These steps were diagrammed using Microsoft Visio 2007 Professional.

3.5. Post Hoc Project Plan Analysis

Upon project completion, reflection on the project plan gives insight into how to make the next project better. This section analyzes the project plan to identify points for improvement and aspects that were effective in project completion.

There were several aspects of the project plan that assisted in project completion. First was project breakdown. Breaking the project into phases and identifying tasks within each phase allowed for a regimented attack strategy and helped identify critical dependencies. For example, database modeling in the creation phase was dependant on specification sheet development in the design phase. Identifying critical dependencies between these aspects and others allowed advanced knowledge of interconnected deliverables and tasks and how and when they needed to be finalized. This led to logical and sequential project execution. The second part of the project plan that was effective was scheduling. The rigorous schedule outlined expected completion times for phases and individual tasks within phases. This helped keep the project on track by defining allotted time for phases and tasks.

Aspects of the project plan that could have been improved were the risk assessment, testing strategy, and requirements documentation. Several risks were identified early in the project. Once these were initially acknowledged and the project plan was adjusted, little effort was made to modify or adjust the overall project plan as new risks arose. Once new risks were identified, on-the-fly piecemeal fixes were applied. A thorough analysis of risks would have made this project easier to complete. The testing strategy could also have been more fleshed out. Testing strategies were defined before enough information about data and software had been acquired. Discussion with the PLTS Nautical Solution developers and testers regarding the methods they use could have assisted in defining testing approach and documentation better. Requirements documentation was initially fraught with misconceptions. Early on, the project suffered due to miscommunication with the client. These issues were worked out within several weeks, but project requirements should have been agreed upon from the start.

4. Database Design

The main focus of this project was to design a database to store MEP MIO data. Several considerations needed to be made for this database to provide value to the client. First was the geometric representation of the new features. Second, the implemented database model needed to be able to interact with the current ENC database to ensure data coincidence. Third, the S-57 standards needed to be fully supported and incorporated in the database design. Finally, the choice between enterprise and personal versions of ArcGIS geodatabase was a minor consideration. These considerations directed and focused all levels of database modeling. Modeling was undertaken at the conceptual, logical, and physical levels. Each level of design is documented in the sections below.

4.1. Conceptual Database Design

As discussed in previous chapters, ENC and MIO data must adhere to the international standards for hydrographic data transfer and dissemination known as S-57. These standards inform product specifications and encoding guides for ENC products. The ENC standards have been developed and frozen for a variety of reasons, and taken as immutable for this project. At this writing the MEP MIO specification sheet is still under development by several hydrographic communities and submitted drafts are under consideration by CHRIS. Because these encoding guides specify objects, attributes, allowable attribute values, and data types for attributes, these documents lend themselves readily and serve quite well as conceptual database models. For this project, the draft encoding guide submitted for review to CHRIS by NOAA was used as a base to build onto. This specification sheet identified core features and their attributes to be used for MEP MIOs. The client wanted the new features to also include attributes useful for marine conservationists. In order to meet this requirement a concerted effort was made to identify common environmental measurements used by marine conservationists. Several marine monitoring handbooks and manuals were consulted to define these attributes. Once relevant attributes were determined, a new specification sheet was compiled for the objects. Figure 6 shows an example of the specification sheet for coral reefs, which can be found in its entirety in Appendix A.1. Attributes listed in Set Attribute A in blue are the attributes added for marine conservationists. This document outlines the types of objects permissible for use in MEP MIO. It does not document geometric representation which was a main consideration identified by the client for the database design and addressed in sections 4.2 and 4.3.

An attribute specification sheet was also created to more thoroughly define the attributes used by MEP MIOs and to provide a greater level of detail, modeled on the draft submitted by NOAA. This sheet documents relevant aspects of each of the newly added attributes. It defines the attribute, data types, minimum and maximum values for rage domains, values for coded value domains, unit of measurement, and resolution of measurement, as well as providing examples and remarks. Figure 7, shows an example of one attribute specification. The entire specification is included in Appendix A.2.

The object and attribute specification sheets defined MEP objects and attributes at a more general level. As such, they are considered to be and used as the conceptual database model. These documents were submitted to the client after completion. After discussion and review with the client the documents were finalized and accepted. From here logical database design and implementation started, guided by these documents.

Geo Object Classes

Object Class: Coral Reef

Acronym: **crlref** Code: 30500

Set Attribute_A:	catref; crlzne, geostr, COLOUR, NATSUR, NATQUA; NOBJNM; OBJNAM; pH; DISOXY; TEMP; SALIN; LTRNS; SUSMAT; BACCON; BLEACH; DISEAS; CRNTDR; CRNTVL, CRLNME
Set Attribute_B:	INFORM; NINFOM; NTXTDS; PICREP; SCAMAX; SCAMIN; TXTDSC;
Set Attribute_C:	RECDAT; RECIND; SORDAT; SORIND;

Attribute Definitions:

Attribute Set A: These attributes define the individual characteristics of an object

catref: Category of reef Code: 30503

Attribute type: E

Coded Value: Domain

1: fringing reef
2: barrier reef
3: reticulated reef:
4: patch reef
5: uplifted reef
6: lagoon
7: atoll
8: coral head
-32767: Unknown

crlzne: Coral Ecological Zone Code: 30507

Attribute type: E
Coded Value: Domain

1: Shoreline Intertidal
2: Lagoon
3: Bank/Shelf
4: Back Reef
5: Ridges and Swales
6: Reef Crest
7: Fore Reef
8: Vertical Wall
9: Bank/Shelf Escarpmen
10: Channel
11: Dredged
12: Land
-32767: Unknown

Figure 6. Excerpt from the MEP MIO Object Catalog

Feature Object Attribute

Attribute: pH

Acronym: pH code: 30518

Attribute type: F

Definition:

The measure of acidity or alkalinity of the water at or around a coral reef

Minimum value: 1

Maximum Value: 14

Indication:

Unit: pH

Resolution: .1pH

Format:

xx.x

Example:

7.0 for a neutral solution

Remarks:

This attribute was identifies as significant and meaningful for Coral Reef monitoring in the Australian Institute of Marine Conservation Handbook

Figure 7. Excerpt from the MEP MIO Attribute Catalog

To create the specification sheets several tasks were completed. First was an investigation of the current standards and specification sheets. Second was researching what marine conservationists are interested in knowing about coral reefs and marine protected areas and measurements they take that could be used for analysis, either temporally, spatially or both temporally and spatially. Third was the compilation of previously and newly defined attributes, attribute values and features.

Investigation of current S-57 standards and ENC specification sheets yielded positive results. The documents reviewed detailed all aspects of S-57 standards including data models, data structures, and storage parameters and includes; catalog of permissible objects and attributes. The ENC specification sheet gave insight into formal presentation objects and attribute definition. Review of these documents took longer than expected because they were filled with domain vernacular and data structures that were not familiar.

During this investigation it was discovered that the NOAA had worked on and submitted a draft MEP MIO encoding guide to CHRIS. Julia Powell, NOAA Technical Director for ENC Development, Marine Chart Division, provided a copy of the prototype MEP MIO specification sheet that was submitted. This was used as a foundation for the extended MEP MIO specification sheet encompassing marine conservationist needs.

During research on marine conservationist activities and monitoring, several strategies were used. The first strategy was to review case studies of marine conservationists using geographic information systems. This yielded few results. Most of the articles focused on praising GIS for its ease of use and utility but provided little information about what the conservationists were measuring, how and at what scale they were measuring, and the units that were being used which is important information for data modeling. None of the reviewed case studies discussed the pitfalls or issues encountered while using GIS in any of the projects. This information was not very useful for defining specifications.

Another method that was considered was conducting personal interviews with marine conservationists and using questionnaires. Precursory work was done for this research technique but it was quickly realized that time and resource constraints prohibited this approach.

The third and final approach, which was also the one that yielded the best results, was to review marine conservationists' handbooks, manuals, survey techniques, and coral reef status reports for the region of and around the study area. In all, 15 manuals, handbooks, and reports were reviewed. These included reports and manuals from the highly revered Australian Institute of Marine Science. Research yielded 12 additional coral reef attributes and associated range or coded values that could be used to extend the MEP specification sheet; see the data in blue type in Figure 6, Appendix A.1, and Appendix A.2.

Once these attributes had been identified, a new MEP MIO specification sheet was drafted using the recently defined attributes, as well as the existing objects and attributes. This document was composed of an object and attribute catalog (Appendix A.1 and A.2, respectively). These documents mimic the style and content of the draft NOAA specification sheet and ENC specification sheet, and define the information in an implementation independent form. This completed document was submitted to the client for review.

The client provided feedback on the specification sheet. Most notable were the changes to the attribute catalog. These included modifications to the measurement units for salinity, suspended matter, value ranges for temperature, and average buffer distance. These changes were made to the appropriate attributes in both specification sheets and the client approved these documents.

The design of these specification sheets were guided by S-57 standards and principles. Most notable was the use of S-57 attribute types and naming conventions. The additional coral reef attributes, with exception of pH, all conform to the six-character naming convention. The attributes themselves conform to S-57 attribute types, and the coding scheme used in the specification sheet is an extension of the ones already established. This was also important when it came time for XML product creation for import and export.

Creating these specification sheets served two purposes. First, as discussed above, is to have an extended MEP MIO specification sheet that defines attributes and objects permissible for use and is geared toward marine conservationists. The second purpose is that it serves as a conceptual coral reef and MPA object model.

As it pertains to database modeling, the specification template abstractly defines objects and attributes. Having a definition of all the objects and attributes allowed for decisions on how best to implement them. This was the focus of logical and physical database modeling and is discussed in following sections.

4.2. Logical Database Design

Logical database modeling shows how phenomenon of interest can be digitally realized in a GIS at a software independent level. Often UML diagrams are created to represent the preferred digital realization of these features. UML models are especially useful because they lend themselves to direct mapping of schema into object oriented language as well as other formats, such as XML and XMI (usable by ArcGIS) (Shekhar, 2003). This design method was employed for logical database modeling.

The first consideration was to determine how best to store the MIO data so that it could work together with ENC data. This was critical to provide seamless integration of the datasets from each database. Several strategies were explored. For the implementation, an ArcGIS Personal Geodatabase was used as directed by the client for proof of concept. This constrained the options presented below.

The first database design considered would have involved creating a standalone database. This strategy would have stored the MEP MIO data separately from ENC data. The best assurance of data overlay or coincide would have been utilizing snapping (an automatic editing operation in which features within a specified distance of other features are moved to coincide exactly with each others' coordinate (Wade, 2006)) when editing datasets and the use of matching projections. This method did not provide enough assurance of proper data overlay and was dismissed as a possible solution for data storage.

The second plan was to integrate the new MEP MIO features with the main ENC features that generally store coral reef and MPA related information. This storage option would have allowed for topological rules to be employed for maintaining proper coincidence between MEP MIO and ENC data. This option would have also assured coincidence through the methods described in the previous design. This method was dismissed for two reasons. First was the enhanced ENC cell deliverable. Storing MIO data outside the ENC database creates issues that result from database integration during export that was outside the scope of this project. Second, storing MEP MIO data and ENC features that currently represent coral reef and MPA features along with ENC data for the same area in an external database creates redundant data. These redundancies would have the capability to cause inaccuracies in the data through any inconsistencies between the features common to the two databases.

The third option was full MEP MIO feature integration with the ENC database. This option provided the most robust data management capabilities. This option allowed for digitizing snapping, topological rule implementation, and reduced data redundancy. This was decidedly the best method, and this approach was used for logical database modeling.

The current ENC geodatabase model was used as a base for logical database modeling. The client provided the Microsoft Visio ENC UML class diagrams used to create the ENC geodatabase template for the newest ArcGIS and PLTS Nautical Solution software release (9.3). This model consisted of all the features classes, attributes, domains, relationship classes, and the hierarchal structure used to create the ENC geodatabase template. Extending this model to incorporate the features identified in the conceptual modeling phase – using the third option mentioned above – completed this phase.

The first model extension created entirely new feature classes within the database to store coral reef and MPA objects. Diagrammatically, these new features were stored with the Natural Features class and the Regulated Areas and Limits class. Each new object had three geometric representations: point, line, and polygon. To most effectively represent two different polygon objects for each of the two features – the feature itself and a buffer area surrounding it – different classes were created. This strategy was favorable as it created a storage container for each feature using different geometric representations. The individual objects contained all the attributes that described them, and features inherited only PLTS-critical attributes from abstract classes. Figure 8 is an example of the first logical database model class diagram. This diagram shows the Coral Reef features as individual classes represented as point, line, and polygon features. The hierarchal structure and the abstract classes represented here contain attributes that are inherited by all feature classes. These attributes are not the focus of this project and the diagram has been truncated to show only relevant features and attributes.

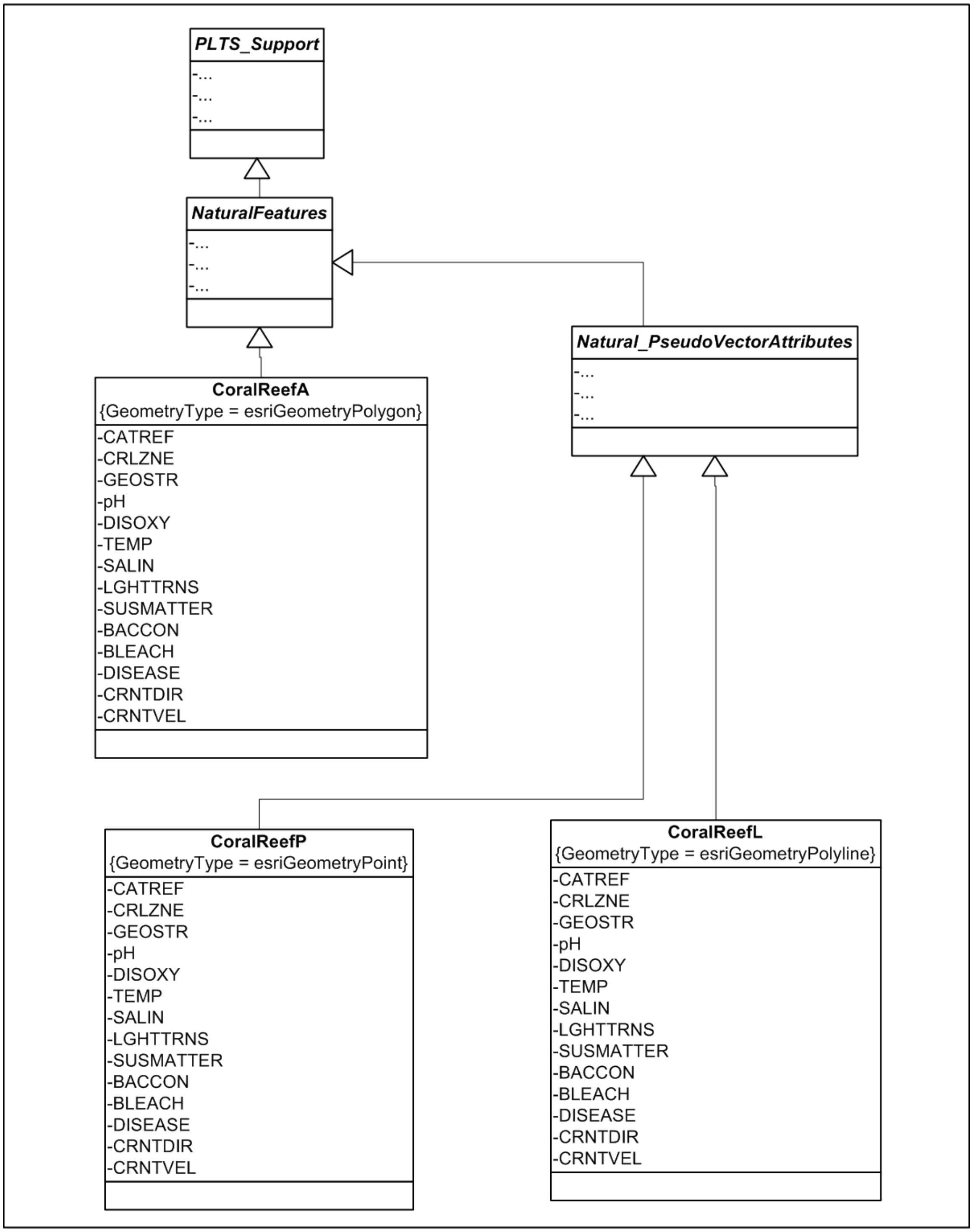

Figure 8. Excerpt from First Logical Database Model

From here, composite relationship classes implementing cascade delete could be built. These relationship classes would link the different geometries that represented single features together for data management purposes.

This initial diagram was submitted to the client for review. Although this design captured the essence of coral reef and MPA integration into the database, the design fell short, according to the client's perspective. During discussions with the client the decision was made that to best utilize PLTS Nautical Solution, another design needed to be developed.

The second attempt at logical database modeling more appropriately represented the new features. This diagram utilized and built onto the existing classes in the original diagram. New subtypes were integrated with the existing features as opposed to creating entirely new classes. MPA and coral reef attributes were stored in the abstract class at an elevated level in the hierarchal structure. This effectively prescribed all coral reef and MPA attributes to all of the classes lower in the hierarchy, though not all the classes needed or should have contained these attributes. This problem is mitigated in the PLTS application and knowledgebase through the use of a filed filter table; which is discussed more thoroughly in section 5.2. Figure 9 shows an example of the second diagram. Notice the change from attribute storage within individual classes to attribute inheritance, as well as the use of subtypes within existing classes. This strategy was used to complete the database diagram for the new coral reef and MPA features.

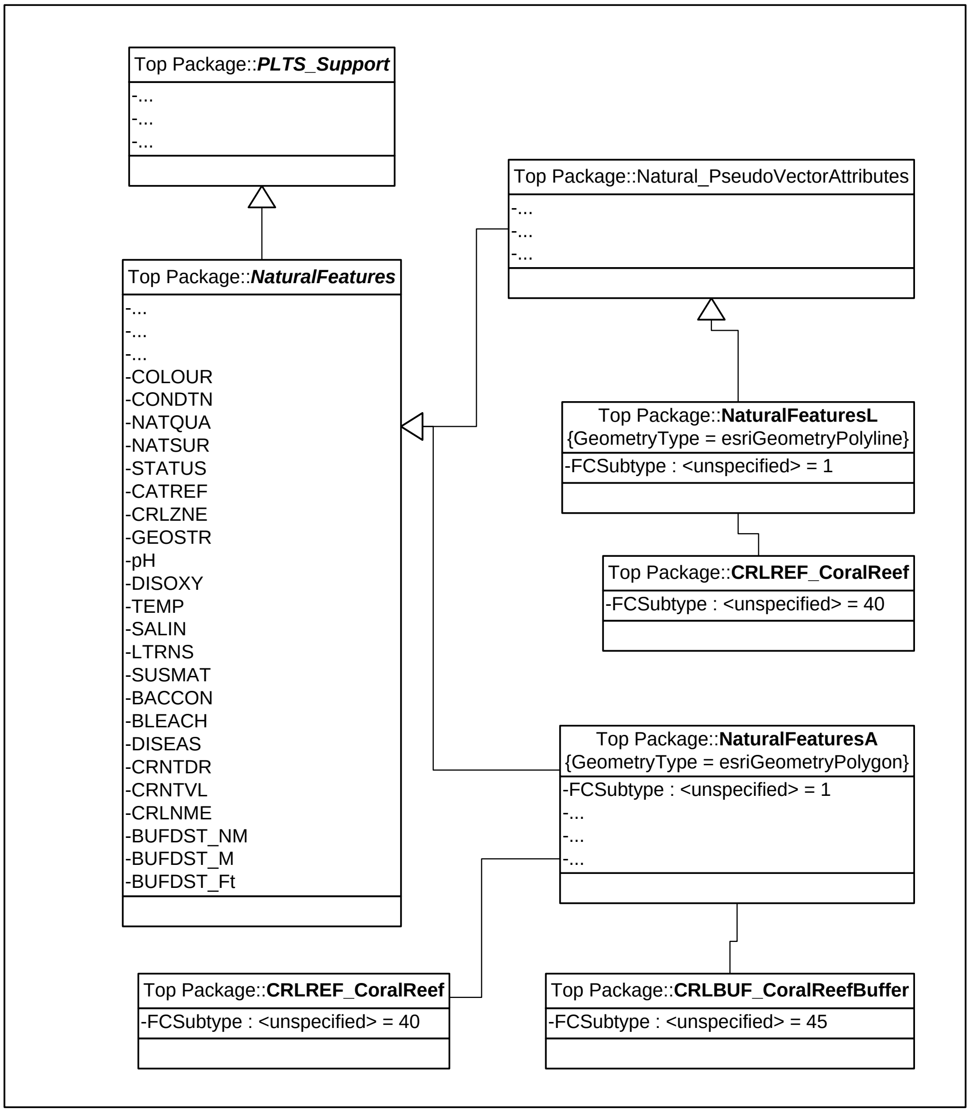

Figure 9. Excerpt of Second Logical Database Model

Once the features were created and appropriate attributes from the specification sheet were included in the abstract classes, the diagram was submitted to the client. Approval for this model was given and further development continued.

To assist in maintaining consistency of data, domains were created for attribute values. These domains were developed from the attribute specification sheet and came in two flavors: coded value and range. Figure 10 shows two domain examples, one of each type.

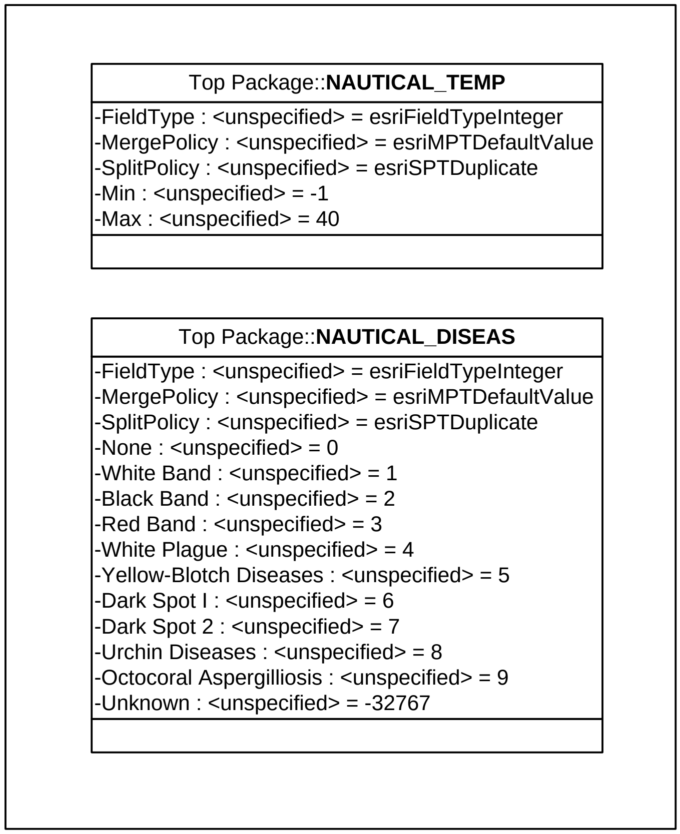

Figure 10. Excerpt of Range Domain (Top) and Coded Value Domain (Bottom)

Once the domains were created, they were applied to the appropriate attributes in the abstract class, as shown in Figure 11. The entire logical database model without existing ENC database aspects is available in Appendix B.

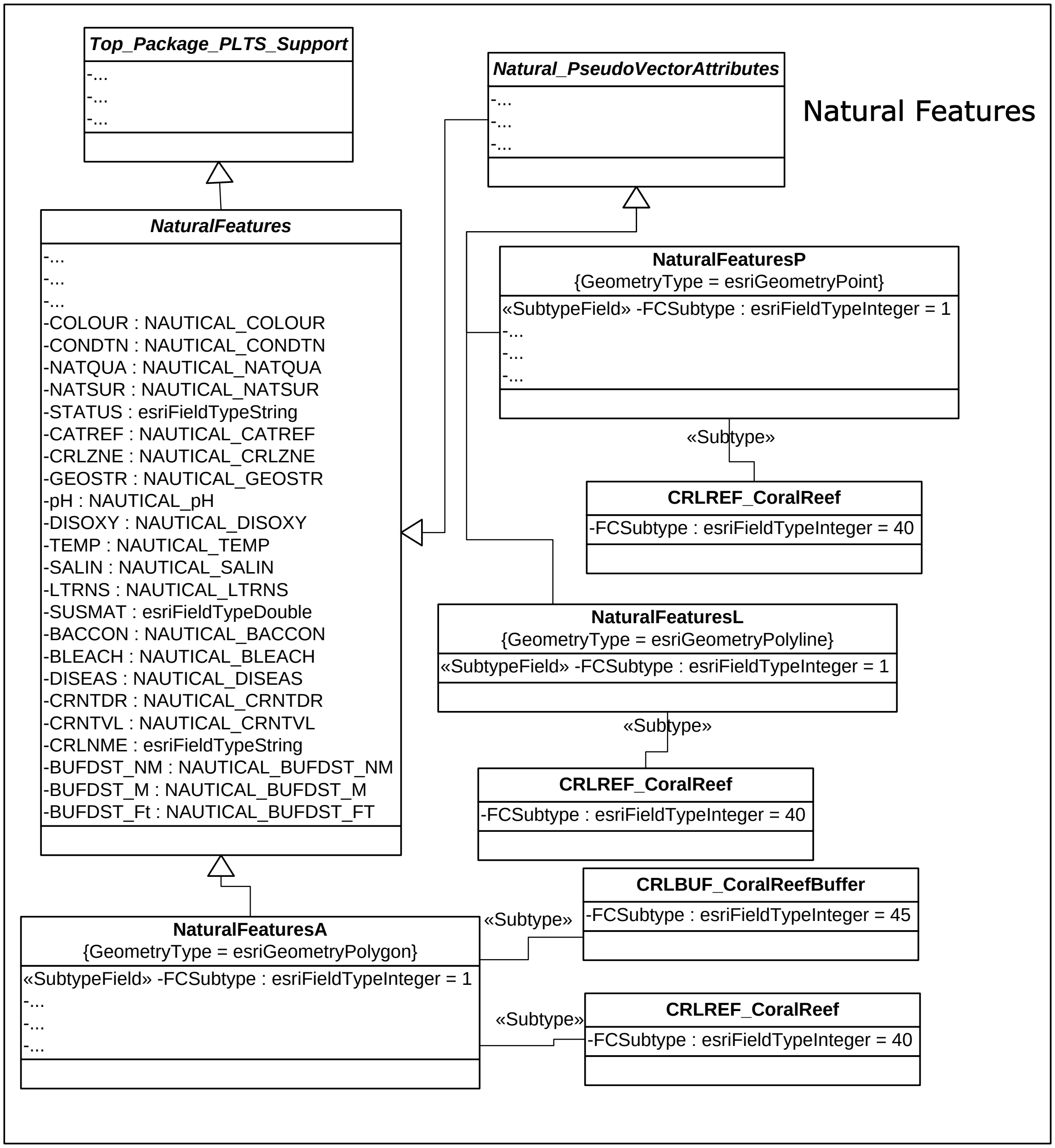

Figure 11. Excerpt of Logical Database Model after Domain Integration and Client Approval

4.3. Logical Database Implementation

In line with the database design mentioned above, additional subtypes were added to six feature classes: Natural Features Point, Line, and Area and Regulated Areas and Limits Point, Line, and Area. Subtypes in Visio are added as new classes. To specify the class as a subtype of another class, there were two requirements. First there must be a common attribute between the two classes; this is used as the primary and foreign key. For this database model, the attribute FCSubtype was used as the common field. This attribute was declared in the class and subtype class. For the super class the FCSubtype attribute is declared as an integer with a stereotype specifying this attribute as a subtype field that links the subtype to the super class.

Second, is a stereotyped association linking the super class and subtype class. Like the subtype attribute in the previous class example, the stereotype of the association is also a subtype. The cardinality of the association for subtypes is always set to many-to-many. This is necessary for the XMI exporter in Visio to create a document readable by ArcGIS tools. This method was followed when adding each of the eight new subtypes.

Appending the appropriate feature attributes to the model came in two parts. First was adding the attribute itself to the data model, and second was creating and applying the appropriate coded value or range domain where applicable.

Adding new attributes to the data model was fairly straightforward. This data model breaks down attributes into several sets in an inherited hierarchical structure. General-purpose attributes for PLTS and S-57 standards are held in high-level abstract classes inherited by all classes in the data model. Class-specific attributes are held in an abstract class one level above the object class representing a feature (the class that is the parent of a subtype class). In order to apply the new attributes to their respective classes, the class-specific abstract classes were located. Figure 13 shows an example of the Natural Features abstract class, which contains all the class-specific attributes for the feature.

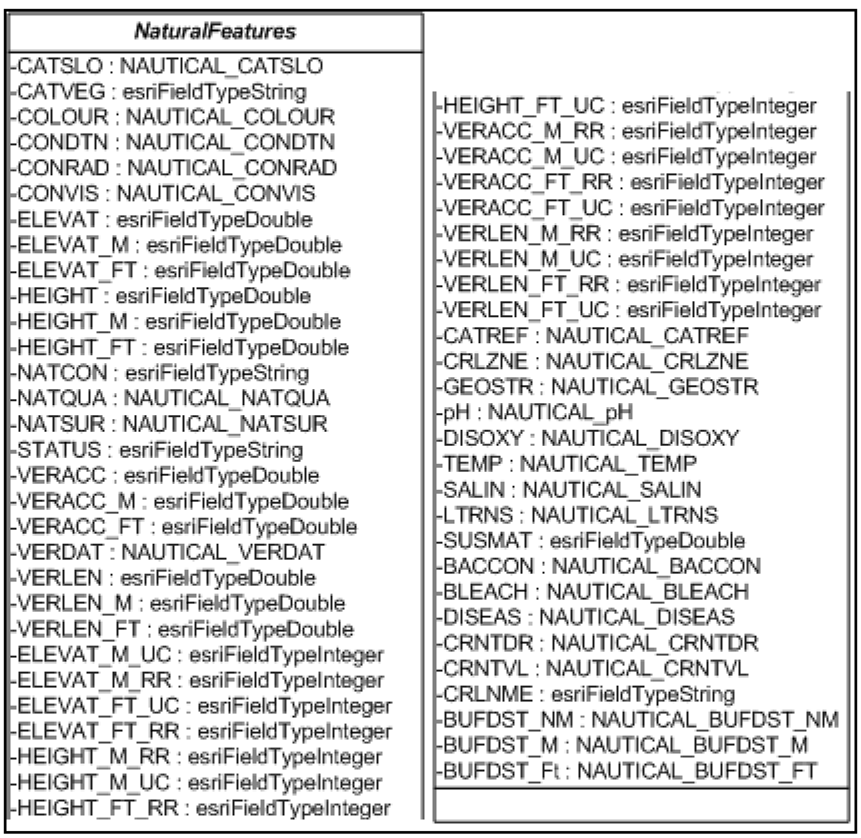

Figure 12. Natural Feature Abstract Class with Class Specific Attributes

Once the abstract class was located, adding the attributes was a matter of creating new fields and setting their three main parameters: data type, multiplicity and, where applicable, initial value. When creating UML models for use with ArcGIS, the attribute data types used are ESRI product specific. The ESRI specific data types represent all the available data types (e.g., double, strings, short and long integers, and BLOB). These data types are specifically tagged so that when the XML workspace is exported, ESRI products can read and interpret the schema. For all of the new attributes, their data types were set to ESRI data types unless a domain was used by the attribute to constrain its allowable values. The visibility of the all the attributes was set to private. This allows the attributes to be used only by the class for which it is declared. The multiplicity of each attribute was set to 1. This parameter defines the number of data values allowable in an instance of the attribute. Setting this value to 1 helps preserves first normal form of the database, though other PLTS Nautical Solution functionality allows this rule to be broken.

Once all of the attributes had been declared, attribute domains were created and linked to the attributes that utilized them. To create the domains, the following process was used.

First, empty classes were created. Once the class was created and added to the workspace, it was stereotyped as either a coded value or a range domain. For either stereotype there are three mandatory attributes (Field Type, Split Policy, and Merge Policy) and four parameters that need to be set for each attribute (data type, visibility, multiplicity, and initial value).

The field type attribute was used by ArcGIS to link the domain to an attribute. Its data type parameter was set to <unspecified> to give it the flexibility to attach to different types of attribute data types. The visibility is set to Private and multiplicity to 1 for the same reasons mentioned above. The initial value parameter was set to an ESRI product-specific data type of integer. This is the default used for geodatabase modeling using Visio and CASE tools.

The split policy attribute defines how attribute value changes when a feature using a domain is divided into separate features. The data type, visibility, and multiplicity were set to the same values as the field type attribute for the same reasons. The initial value parameter was set to duplicate the domain value of the original feature. This defined that when a feature was divided into separate features the new feature received the default domain value for the attribute.

The merge policy defines how attribute values associated with a domain change when two or more features are combined into a single feature. The data type, visibility, and multiplicity were set to the same values as the split policy attribute for the same reasons. The initial value parameter was set to the default domain value. This assured that the new feature would be attributed with some value and not left null.

This arrangement for the three common domain attributes was used for all the coded value and range domains.

For the two different types of domains (coded value and range), along with the mandatory attribute described above, there needed to be additional attributes created and defined. For a range domain these attributes are the minimum and maximum values. For a coded value domain these are the values and their associated codes. The parameters mentioned above also need to be set for these additional attributes of the domain stereotyped class.

Range domains constrain numeric attribute values to a specific numeric span. Depending on the range being set, the minimum and maximum attributes are different. These two attributes are strictly named min and max in this data model. This allows the XMI workspace defining the domain schema to be read and utilized by ArcGIS. The data type, multiplicity, and visibility parameters were all set to the same values described above. The initial value parameter is used to specify the numeric minimum or maximum values allowable. Depending on the domain and the attribute it was applied to, this parameter was set to values corresponding to those defined in the encoding guide. Figure 13 shows an example of one range domain that was created.

«RangeDomain»**NAUTICAL_SALIN**
-FieldType : <unspecified> = esriFieldTypeInteger -MergePolicy : <unspecified> = esriMPTDefaultValue -SplitPolicy : <unspecified> = esriSPTDuplicate -Min : <unspecified> = 33 -Max : <unspecified> = 36

Figure 13. Water Salinity Range Domain

Coded value domains allow for the storage of descriptive attribute values as integers. For an attribute using a coded value domain, the value is set to a numeric value. This value is related to a table that stores a textual description of the value. This way, an attribute can store very small amounts of data while providing a descriptive definition of what the value means. These domains also assist in attribute consistency. This is done by limiting the possible entries to a defined set. The additional attributes in each coded value domain varied. This was due to the fact that there were different numbers of coded values. For each coded value two parameters needed to be set. The name of the attribute defines the description of the numeric entry and the initial value identifies the code. Depending on the domain and the attribute it was applied to, the additional attribute and its initial value parameter were set to correspond to those defined in the encoding guide. Figure 14 shows an example of one coded value domain that was created.

«CodedValueDomain»**NAUTICAL_DISEAS**
-FieldType : <unspecified> = esriFieldTypeInteger -MergePolicy : <unspecified> = esriMPTDefaultValue -SplitPolicy : <unspecified> = esriSPTDuplicate -None : esriFieldTypeSmallInteger = 0 -White Band : esriFieldTypeSmallInteger = 1 -Black Band : esriFieldTypeSmallInteger = 2 -Red Band : esriFieldTypeSmallInteger = 3 -White Plague : esriFieldTypeSmallInteger = 4 -Yellow-Blotch Diseases : esriFieldTypeSmallInteger = 5 -Dark Spot I : esriFieldTypeSmallInteger = 6 -Dark Spot 2 : esriFieldTypeSmallInteger = 7 -Urchin Diseases : esriFieldTypeSmallInteger = 8 -Octocoral Aspergilliosis : esriFieldTypeSmallInteger = 9 -Unknown : esriFieldTypeString = -32767

Figure 14. Coral Diseases Range Domain

In all, 23 domains were added to the data model during the creation phase. This consisted of 11 range domains and 12 coded value domains. The specification sheet for MEP MIOs guided the creation of the class subtypes, domains, and additional attributes.

Once the domains were created, they were applied to the appropriate attribute in the abstract classes. This was done by setting the data type for an attribute to that of the domain. Figure 15 shows an abstract class; attributes set to ESRI data types are circled in red while attributes with a domain set as the data type are not.

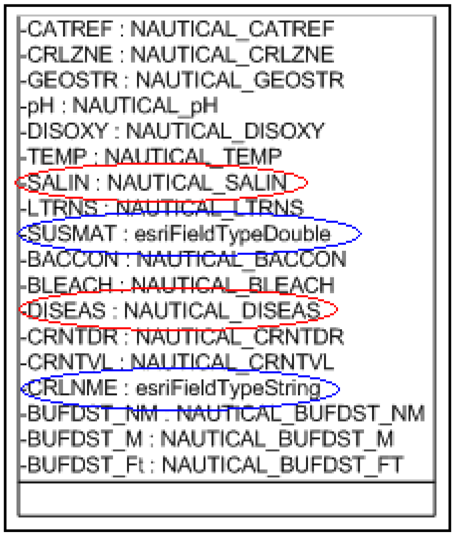

Figure 15. Abstract Class with Attributes Set to ESRI Data Types (Blue) or Created Domains (Red)

Once all the subtypes and domains were created, the UML data model was exported using a two-step process. The first step of exporting to an XMI is documented in section 4.5 on physical database modeling. The second step, semantic checking, is concerned with the validation of the database schema for ArcGIS use. This second step is discussed below, as it pertains to finalizing logical database design.

The semantic checker is initiated through a drop-down menu in Visio. Running this tool produces a summary log file of semantic errors and warnings. The semantic checker validates the schema against ESRI-compatible XMI tags. The tool is used to verify that the structure of the data model is in line with that of a geodatabase and that the XMI produced during export will be fully readable by ArcGIS.

When this tool was first run on the completed data model, 17 errors were reported along with several hundred warnings. The warnings were not addressed since the same warnings came up when the semantic checker was run on the original model. On the other hand the errors needed to be dealt with. There were three types of errors specified: invalid domain specification, duplicate attribute names in an abstract class, and invalid attribute domain specification.

The invalid domain specification error pointed out eight incorrectly specified domain parameters. On investigation, it was found that these errors were caused by misspellings in the field type initial value parameter. The spelling was corrected and the semantic checker was run again. These errors were not recorded in the semantic checker log file the second time around.

The invalid attribute domain specification error was looked at next. This error was tied to the invalid domain specification error. Specifically, this error flagged the domains tied to attributes versus the domains themselves as in the previous error. Once the misspellings were fixed for the invalid domain specification error and the semantic checker run again, these errors were not reported in the log file.

The duplicate name in an abstract class error was the final error to be looked at. The RESTRN attribute, which had already been added to the Regulated Areas and Limits abstract class, was causing this error. Once the redundant attribute name was removed, the semantic checker was run a third time. On completion of running the semantic checker, the error was not reported in the log file.

With all the errors fixed, the semantic checker was run a final time to ensure no new errors were created and that none of the old ones remained. The final semantic check yielded no errors and database export ensued. This document was submitted to and accepted by the client. With client approval gained, logical database modeling was completed and the physical database work began.

4.4. Physical Database Design

Once logical database modeling had been completed and approved by the client, physical modeling was the last step in bringing the database to fruition. Logical database modeling is used to define exactly the files and tables used to store the data. Other steps in physical database modeling include defining relationships between objects and determining the operations that can be performed. Because this database was implemented using a geodatabase and additional relationship classes were not needed, minimal work in the latter two areas relationship and object operation definition was undertaken.

The logical database model was born strictly out of the physical model. Microsoft Visio and ESRI provide the functionality to semantically check UML models to ensure readability of ESRI products. This means that through validation of the UML structure and Visio/ESRI export functionality, XMI schemas can be created that are directly readable by ArcGIS. This allows UML diagram schema to be used to create a geodatabase.

To create a physical data model – in this case a geodatabase – from the UML diagram in Visio, a two-step process is followed. An XMI schema document was created by Visio. During this process, a log file is created to document any errors or warnings. Once this schema is created, an ArcGIS add-on is used to read the XMI document schema and translate it into the formal structure of a geodatabase. This process is discussed more thoroughly in section 4.5.

Figure 16 shows the geodatabase template created from the XMI schema. This figure is the representation of the fact that the database was created from an XMI schema produced from exporting a UML diagram. This figure also shows the shift from a platform independent database model to a specific instance of the database realized in a specific software system.

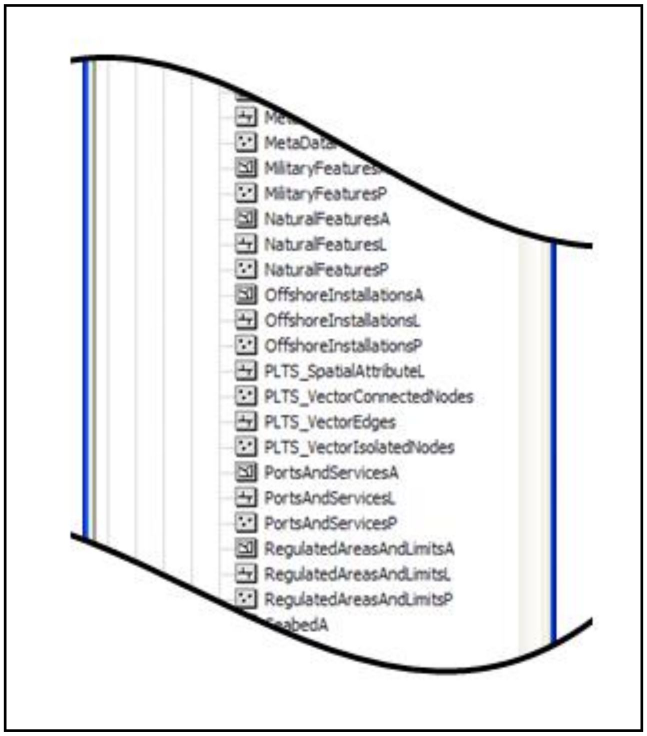

Figure 16. Excerpt from Resultant Geodatabase Template from XML Schema

Figure 17 shows the schema from the geodatabase template shown above in figure 16. Figure 17 figure shows the schema of the Natural Feature Point feature class in the geodatabase and the relationship to the subtype identified in the UML.

Simple feature class
NaturalFeaturesA

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field name	Data type	Allow nulls	Default value	Domain	Prec-ision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
...	...	...					...
...	...	...					...
...	...	...					...
FCSubtype	Long integer	Yes	1		0		
Shape_Area	Double	Yes			0	0	

Subtypes of NaturalFeaturesA

Subtype field *FCSubtype*
Default subtype *1*

List of defined default values and domains for subtypes in this class

Subtype Code	Subtype Description	Field name	Default value	Domain
40	CRLREF_CoralReef	COLOUR		NAUTICAL_COLOUR
		CONVIS		NAUTICAL_CONVIS
		NATQUA		NAUTICAL_NATQUA
		NATSUR		NAUTICAL_NATSUR
		CATREF		NAUTICAL_CATREF
		CRLZNE		NAUTICAL_CRLZNE
		GEOSTR		NAUTICAL_GEOSTR
		pH		NAUTICAL_pH
		DISOXY		NAUTICAL_DISOXY
		TEMP		NAUTICAL_TEMP
		SALIN		NAUTICAL_SALIN
		LTRNS		NAUTICAL_LTRNS
		BACCON		NAUTICAL_BACCON
		BLEACH		NAUTICAL_BLEACH
		DISEAS		NAUTICAL_DISEAS
		CRNTDR		NAUTICAL_CRNTDR
		CRNTVL		NAUTICAL_CRNTVL
		BUFDST_NM		NAUTICAL_BUFDST_NM
		BUFDST_M		NAUTICAL_BUFDST_M
		BUFDST_Ft		NAUTICAL_BUFDST_FT

Figure 17. Natural Feature Point Feature Class Schema

4.5. Physical Database Implementation

To begin the physical database modeling phase, a third and final logical database model semantic check was run. This was to again verify that the schema of the database model, upon export to XMI, was readable by ESRI software. This check returned no errors. The rest of the logical database design work was completed in two parts: the creation of a physical database (a geodatabase) and an examination of the database to ensure all features, subtypes, attributes, and domains were created properly.

The creation of the database was completed in a two-step process. First was to export the UML database model to an XMI document; second was to import this XMI document through ArcCatalog and create a geodatabase from it.

To export the database to an XMI, a Visio add-on is available from Microsoft. This add-on was downloaded and the Visio diagrams and .dll files were placed in their proper folders. The add-on was added to the GUI through the Customize Tools dialog per the documentation. This tool reads the database model schema and produces a tagged XMI document that specifies all aspects defined in the UML model. The tool is a simple point-and-click execution. Figure 18 shows an example of the XMI document. This excerpt of code is describing the Coral Reef point subtype of the Natural Feature feature class.

```
    <Foundation.Core.Classifier.feature>
      <Foundation.Core.Attribute xmi.id="UIDDF5B9221-E089-4FC7-93A5-DAE5BF801B5D">
        <Foundation.Core.ModelElement.name>FCSubtype</Foundation.Core.ModelElement.name>
        <Foundation.Core.ModelElement.visibility xmi.value="private"/>
        <Foundation.Core.Feature.ownerScope xmi.value="instance"/>
        <Foundation.Core.StructuralFeature.multiplicity>1</Foundation.Core.StructuralFeature.multiplicity>
        <Foundation.Core.StructuralFeature.changeable xmi.value="none"/>
        <Foundation.Core.StructuralFeature.targetScope xmi.value="instance"/>
        <Foundation.Core.Attribute.initialValue>
          <Foundation.Data_Types.Expression>
            <Foundation.Data_Types.Expression.language/>
            <Foundation.Data_Types.Expression.body>1</Foundation.Data_Types.Expression.body>
          </Foundation.Data_Types.Expression>
        </Foundation.Core.Attribute.initialValue>
        <Foundation.Core.StructuralFeature.type>
          <Foundation.Core.DataType xmi.idref="UID342DA075-D1BE-11D2-9F2E-00C04F6BDF1A"/>
        </Foundation.Core.StructuralFeature.type>
        <Foundation.Core.ModelElement.taggedValue>
          <Foundation.Extension_Mechanisms.TaggedValue xmi.id="UIDD5ABDAE5-76B9-4421-A9EC-F7301F567F47">
            <Foundation.Extension_Mechanisms.TaggedValue.tag>persistence</Foundation.Extension_Mechanisms.TaggedValue.tag>
            <Foundation.Extension_Mechanisms.TaggedValue.value></Foundation.Extension_Mechanisms.TaggedValue.value>
          </Foundation.Extension_Mechanisms.TaggedValue>
        </Foundation.Core.ModelElement.taggedValue>
        <Foundation.Core.ModelElement.taggedValue>
          <Foundation.Extension_Mechanisms.TaggedValue xmi.id="UID78E5A31C-037B-47AC-90B0-ABC42EC2DF94">
            <Foundation.Extension_Mechanisms.TaggedValue.tag>documentation</Foundation.Extension_Mechanisms.TaggedValue.tag>
            <Foundation.Extension_Mechanisms.TaggedValue.value></Foundation.Extension_Mechanisms.TaggedValue.value>
          </Foundation.Extension_Mechanisms.TaggedValue>
        </Foundation.Core.ModelElement.taggedValue>
      </Foundation.Core.Attribute>
    </Foundation.Core.Classifier.feature>
  </Foundation.Core.Class>
  <Foundation.Core.Class xmi.id="UID350304EC-2989-4031-A34B-2D52275F5FAA">
    <Foundation.Core.ModelElement.name>CoralReefP</Foundation.Core.ModelElement.name>
    <Foundation.Core.ModelElement.visibility xmi.value="public"/>
    <Foundation.Core.GeneralizableElement.isRoot xmi.value="false"/>
    <Foundation.Core.GeneralizableElement.isLeaf xmi.value="false"/>
    <Foundation.Core.GeneralizableElement.isAbstract xmi.value="false"/>
    <Foundation.Core.Class.isActive xmi.value="false"/>
    <Foundation.Core.ModelElement.namespace>
      <Model_Management.Package xmi.idref="UID1C4176A1-6116-4958-A4F3-FABB5DA4CD08"/>
    </Foundation.Core.ModelElement.namespace>
    <Foundation.Core.ModelElement.taggedValue>
      <Foundation.Extension_Mechanisms.TaggedValue xmi.id="UIDDD1BCDFB-DAAD-4209-A28F-6D980CAB8798">
        <Foundation.Extension_Mechanisms.TaggedValue.tag>documentation</Foundation.Extension_Mechanisms.TaggedValue.tag>
        <Foundation.Extension_Mechanisms.TaggedValue.value></Foundation.Extension_Mechanisms.TaggedValue.value>
      </Foundation.Extension_Mechanisms.TaggedValue>
    </Foundation.Core.ModelElement.taggedValue>
    <Foundation.Core.ModelElement.taggedValue>
      <Foundation.Extension_Mechanisms.TaggedValue xmi.id="UIDFF6CF0E0-8B57-4235-85DF-A6C66AA6D9E2">
        <Foundation.Extension_Mechanisms.TaggedValue.tag>responsibility</Foundation.Extension_Mechanisms.TaggedValue.tag>
        <Foundation.Extension_Mechanisms.TaggedValue.value></Foundation.Extension_Mechanisms.TaggedValue.value>
      </Foundation.Extension_Mechanisms.TaggedValue>
    </Foundation.Core.ModelElement.taggedValue>
```


Figure 18. XMI Document Describing a Subtype of the Database

Once the XMI document, from figure 18, was created, it was used to create a blank geodatabase template. This was accomplished by using the CASE schema creation extension from ESRI. This extension was downloaded from the ESRI Web site and installed according to its documentation. The tool was added through the Customize dialog box.

When the tool was executed, a wizard appeared that walks the user through the process. The XMI document created from the UML model was specified as the source schema. The wizard then opened a dialog box that allows the user to examine the database before it was created. Checks were made to ensure that the additional subtypes, attributes, and domains were all intact, in their proper locations, and specified properly. The tool was then executed and ran for a total of 45 minutes. Once complete, the resultant geodatabase template was examined once again for subtypes, attributes, and domains. With all aspects intact, the physical database modeling and database modeling altogether was complete.

4.6. Database Conclusions

Database modeling was an important part of this project. Well reasoned and logical database structure is the first step in maintaining data consistency and geometric coincidence for this project. Hydrographic data standards were utilized and marine conservation attributes were integrated into the database. UML was used for logical database modeling in Microsoft Visio. This logical model was used to produce a schema that was utilized by ESRI ArcCatalog to build a geodatabase template. This template was the physical database model and provides the additional functionality needed to help consistently produce and reproduce MEP MIO data and data overlays.

The database design made two steps toward the consistent production of MIO and Mio data. First through a defined set of objects and attributes the representation of coral reefs and MPAs has been constrained. This constraint was tightened with the creation and application of attribute domains. Second the database design implemented international standards that allow for consistent MIO data representation across software platforms. The database design also made steps to ensuring proper data coincidence. The database was designed for the creation and implementation of topological rules between ENC and MIO data. These rules helped ensure proper data overlay was achieved through using core ArcGIS functionality.

5. Implementation

This section describes the steps taken to complete this project. Documenting what steps were taken and modification made is essential for project reputability and result verification. As described in the project plan, this project was composed of three phases: design, creation, and implementation. The following sections are arranged by phase and task as outlined in the project schedule. Designations are made when one task or phase feeds into another and what tasks are being executed concurrently.

Section 5.1 outlines and describes the completion of the design phase. This section explains the effort to define project requirements and early workflow design work.

Section 5.2 outlines and describes the work effort to complete the creation phase. This section documents the effort to create XML schema documents for two products, configure and modify PLTS and configure the ENC knowledgebase to create an MIO-ENC knowledgebase, define topological rules for geometric consistency, and the creation of MEP MIO workflow.

Section 5.3 documents the work effort to complete the implementation phase. This section explains the effort to put the aspects conceived in the design phase and brought to fruition in the creation phase together. Described in this section are the steps made in implementing and testing XML schema documents, knowledgebase configurations for attribute consistency and constraint, and topological rules for geometric coincidence.

5.1. Design Phase

As mentioned in the introduction, this section describes tasks completed during the design phase and the methods used to carry them out. This section opens with documentation of the process of defining the requirements for the project. This leads into describing the method and work effort for researching and defining the specification sheet for MEP MIOs. This section closes with a description of the precursory work completed for workflow development.

5.1.1. Defining Project Requirements

The requirements for the project were defined during several meetings members of ESRI's global navigation team. Initial meetings were held with MS GIS facility member and former ESRI project manager James Ciarrocca. This provided background and a third-party perspective on the team, its work, and what it was looking for from the project. This insight was helpful for initial project definition and problem identification. From here, a phone interview and a follow-up e-mail questionnaire were held with Brian Cross from ESRI. The phone interview drew out some of the main issues that needed to be solved in order for PLTS Nautical Solution to be configured to create MEP MIOs with consistent representation and attribution. These issues were reinforced by the e-mail questionnaire.

The questionnaire asked three questions to provide insight into the problem and the clients' vision of the solution: Question: What is the main problem? Answer: "We want to extend our S-57 ENC support to include MIO support within the PLTS Nautical Solution. The fundamental problem is [with the] database model and software configuration to setup the capability in PLTS Nautical Solution. Additional components include investigating, documenting, and testing workflow associated with managing MIO objects and producing MIO S-57 files, as well as requirements for application development that might support MIO production." Question: What types of additional functionality do you want to implement into the solutions that you provide? Answer:

1. MIO database object (database design/extension to PLTS Nautical S-57 data model)
2. MIO import and export capability in PLTS Nautical Solution, which requires configuring the solution's import/export engine
3. MIO data management workflow (with existing tools) or new tools (written by you or by developers on the team) to enhance the process
4. Documentation/Testing of the capability
5. Lighter-weight MIO viewing capability (ArcGIS Explorer/Google Earth, etc.), probably powered by ArcGIS Server and backend MIO publishing capability

Question: What types of additional functionality do you want to integrate into your current data model? Answer: "Objects, entities, and relationships required to support the MIO standard."

These answers provided the foundation for the rest of the project definition and proposal stages and gave insight into the activities that needed to be completed.

From this point, a project proposal was written. This proposal included relevant literature, problem statement, proposed solution, and deliverables. This document was submitted to the client, Rafael Ponce of the global navigation team, for review.

After reviewing the proposal, another meeting was held to clarify deliverables and work effort. The meeting was held with Dr. Douglas Flewelling of the University of Redlands and Mr. Ponce and it yielded a high level of results and focused proposal redrafting. The final proposal was submitted and approved on January 3, 2008. It was then that system and database design work began, see Chapter 4 for a review of database work.

5.1.2. Precursory Work for MIO Workflows

Creating best practices and workflows for MEP MIO creation provides assurance of consistent production and reproduction of data and S-57-formatted overlays. This task was undertaken later in the project due to task interdependencies. Only after the specification sheet, database, and PLTS configurations were completed or being tested, and an understanding of coral reefs, MPA, The Standard, and PLTS Nautical Solution were obtained could this task begin.

The precursory work for workflow development encompassed all aspects of the project previously undertaken. The Workflow Development subsection of section 5.2.1 documents the development of conceptual MEP MIO workflows.

5.2. Creation Phase

The creation phase consisted of three parts: (1) model and create the database on two levels, logical and physical, see Chapter 4; (2) create the necessary XML documents to allow import and export of MIO data to and from the database into S-57 format; and (3) configure PLTS to account for the new features and domains added to the database during database modeling and creation of platform independent *where* clauses for attribute validation. Completing these aspects fulfilled the major requirements outlined in section 3.2.1 for this project and finalized the creation phase. Parts two and three are discussed below; see chapter 4 for part one, database implementation.

5.2.1. PLTS Nautical Solution Configuration

The second part of the creation phase centered on configuring and customizing ESRI's PLTS Nautical Solution. The configurations were made on two fronts: the XML import/export configuration file and the product knowledgebase. The XML document contains the schema maps that allow S-57 data to be interoperable between its native storage parameters and a geodatabase. The product knowledgebase contains tables that PLTS Nautical Solution uses to perform various attribute and representation validation checks. This section describes how these modifications were made. It took many iterations to get these aspects to work properly. The changes made to these items as the result of testing are documented in section 5.3 and the issues discovered are documented in Chapter 6. This section is mainly concerned with describing the processes that were followed to configure PLTS Nautical Solution. The examples given are from the finished knowledgebase and XML documents.

XML Configuration

The XML documents are used by the PLTS Nautical Solution import/export engine to define the mapping between the features and attributes of the S-57 data structure and the geodatabase template created during physical database modeling. The XML document currently used for this process was extended to account for the additional coral reef and MPA features added to the database. This modification was also necessary to account for the MEP MIO features in S-57 format as defined in the specification sheet.

This task ran concurrently with the previous phases and tasks mentioned above. The precursory work that is documented in the next paragraph took place during the design phase. The structuring and creation of the document ran concurrently with PLTS knowledgebase configurations.

To configure the XML document, an understanding of XML and its syntax and usage was necessary. Research and tutorials from the World Wide Web Consortium (W3C) were completed as well as additional research on the use of XML in attribute mapping (see section 2.2 for more information). Once a better understanding of XML was reached, the current XML schema map was obtained from the client. This document was studied and its structure dissected. The key element of interest for the extension was the product map element. Between the product map opening and closing tags, each S-57 feature and its attributes are mapped to the representative feature and attributes in the geodatabase. Figure 18 shows an example of an object map within the product map element. This example shows the connection and the structure of an object map. Notice that within an object map, there are a couple of things happening. First, the object is mapped between the two data structures. Identified within the S-57 and geodatabase objects, there are several attributes. These attributes define the coded value of the object (specification sheet defined), the type of data that it represents, the group to which it belongs, and the subtype the object will be loaded into. Within the object map element, there are also attribute map elements. These identify the connection between the attributes of the features. In this case, as well, there are attributes of the element. These again identify a coded value of the attribute (specification sheet defined), delineation of the set that the attribute belongs to, a quality control value, and a data transfer definer (the attribute). These elements combine to completely define the relationship between features in different data structures and determine how to transfer the data between the two.

```
</OBJECTMAP>
<OBJECTMAP id="271">
  <S57OBJECT name="C_AGGR" code="400" type="N" grup="2"/>
  <GDBOBJECT name="PLTS_COLLECTIONS" type="T" subtype="C_AGGR_Aggregation" />
  <ATTRIBUTEMAP id="6187">
    <S57ATTRIBUTE name="COLLECTION_TYPE" code="3027" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="COLLECTION_TYPE" />
  </ATTRIBUTEMAP>
```

Figure 18. Object Map Element with One Attribute Map

This structure was duplicated for the new object maps. The new object maps were based on both the specification sheet and geodatabase created previously in the project. Each document was opened and the relationship between the features drawn out using diagramming software. The coding was performed using Architag X-Ray XML and Symbol Click XML Marker. The structure of the objects was written first. This entailed building the hierarchical structure of the elements, tags, and attributes while leaving the values blank. Once the structure had been built, the attribute values (defined between the quotation marks) were populated according to the database schema and specification sheet. The S-57 object maps and attribute maps were populated according to the parameters defined in the specification sheet, while the geodatabase objects and attributes were populated according to the database schema. Figure 19 shows how the elements from the specification sheet and database schema were used to populate the XML document. Figure 20 is an example of one of the new object maps. It shows the mapping between the coral reef feature in S-57 format and the coral reef subtype of the Natural Feature Polygon feature class. An entire copy of the object maps added to the product map element of the XML document is available in Appendix C.

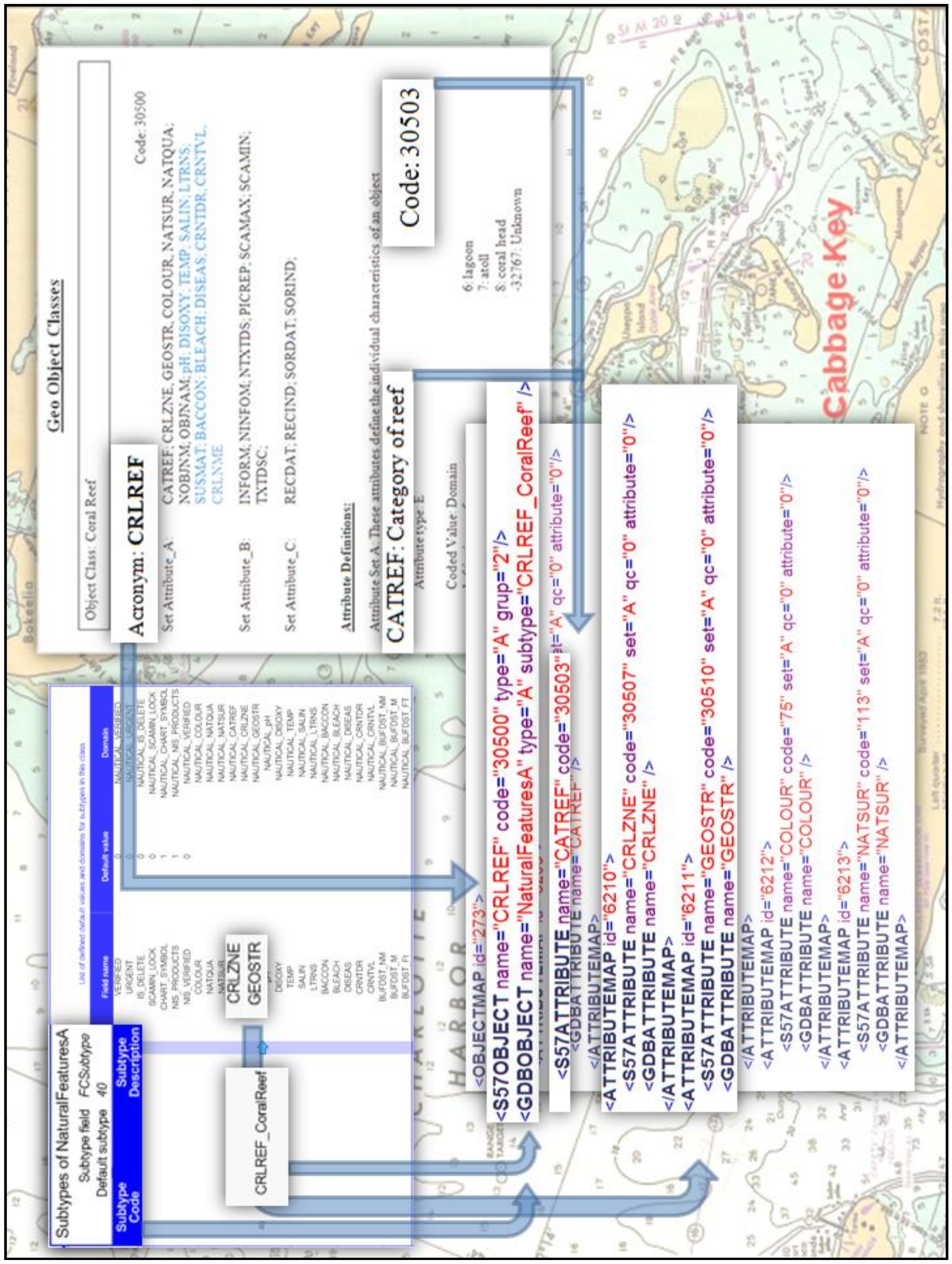

Figure 19. Elements of Database Schema and Specification Sheet Combining to Create XML Document

```xml
<OBJECTMAP id="273">
  <S57OBJECT name="CRLREF" code="30500" type="A" grup="2"/>
  <GDBOBJECT name="NaturalFeaturesA" type="A" subtype="CRLREF_CoralReef" />
  <ATTRIBUTEMAP id="6209">
    <S57ATTRIBUTE name="CATREF" code="30503" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="CATREF" />
  </ATTRIBUTEMAP>
  <ATTRIBUTEMAP id="6210">
    <S57ATTRIBUTE name="CRLZNE" code="30507" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="CRLZNE" />
  </ATTRIBUTEMAP>
  <ATTRIBUTEMAP id="6211">
    <S57ATTRIBUTE name="GEOSTR" code="30510" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="GEOSTR" />
  </ATTRIBUTEMAP>
  <ATTRIBUTEMAP id="6212">
    <S57ATTRIBUTE name="COLOUR" code="75" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="COLOUR" />
  </ATTRIBUTEMAP>
  <ATTRIBUTEMAP id="6213">
    <S57ATTRIBUTE name="NATSUR" code="113" set="A" qc="0" attribute="0"/>
    <GDBATTRIBUTE name="NATSUR" />
  </ATTRIBUTEMAP>
```

Figure 20. Object Map Element Excerpt for Coral Reef in S-57 Format and Features Class Subtype

With all the object maps for the new features completed, XML creation was complete. The resultant XML document should have been able to import S-57 ENC cells into the database and export the database to an ENC cell with enhanced features, functionality of the XML configurations are documented in section 5.3 and Chapter 6. The modifications made to this final document as a result of testing and implementation is documented in section 5.3 of this chapter and the final results are documented in Chapter 6.

The XML product map discussed above would be used to export the entire database to a new ENC cell. But in order to produce a single overlay with only MEP data (coral reefs and MPAs), further modification needed to be made. Because the object map elements in the product map relate all features in the database to S-57 format, many of the object maps were not necessary. To create the MEP MIO-specific XML, these extraneous object maps were simply eliminated. The result is a truncated product map only specifying object maps for MEP features in S-57 format and in the geodatabase. The resultant XML document should have been able to import S-57 MEP MIOs into the database and export the database to a MEP MIO, functionality of the XML configurations are documented in section 5.3 and Chapter 6. The modifications made to this final document as a result of testing and implementation is documented in section 5.3 of this chapter and the final results are documented in Chapter 6.

PLTS Knowledgebase Configurations

PLTS knowledgebase configurations were geared toward aiding the workflow of MIO creation. These modifications endowed the database template with the tables necessary for the PLTS application to constrain editing of MEP MIO data. In order to complete this, three tables of the existing ENC knowledgebase were configured: Field Filter, Master Condition, and Error tables. This resulted in a new edition knowledgebase for MEP overlay data. In addition to the knowledgebase configurations, new topology rules were created to aid workflow by ensuring geometric coincidence. These two aspects, together with the conceptual workflows, created a computer environment that assisted in the consistent production and reproduction of MEP MIO data. The mechanics of these modifications are discussed below and all examples given are from finished products. Any alterations made to the knowledgebase, topology rules, or workflows as a result of testing and implementation are documented and discussed in section 5.3.

Field Filter Configuration:

To begin the knowledgebase configuration, the Field Filters table was modified. The database design that had been chosen integrated the new MEP features into the existing ENC database. This design used hierarchical inheritance to give feature-specific attributes to specific classes and give general-use attributes to all classes. The general-use attributes pertain to S-57 mandatory attributes and attributes used by the PLTS application for symbology, rendering, and data reviewing. Figure 13 shows the natural feature abstract class. These attributes are specific to the Natural Features class but not all are applicable to all Natural Feature Subtypes. The produced database template from export to and import from XMI applies all attributes in classes at elevated level in the hierarchy to all subtypes in a class. This is remedied by the use of the knowledgebase Field Filter table. As the name suggests, this table filters out attributes for display and constrains allowable data entry in ArcMap. This allows for a subset of attributes to be worked on and attributed correctly while others that are automatically populated or protected from editing are blocked.

To modify the Field Filters table, the current knowledgebase was obtained from the client. The knowledge comes in the form of a Microsoft Access database. Access 2007 was used to open and modify the table. When adding to the Field Filter table there were seven attributes that needed to be configured: Feature Class Name, Subtype Code, Field Order, Filed Name, Type Environment, Mask, and Domain Name.

The Feature Class Name attribute identifies the feature class to which these filter record applies. The Subtype Code identifies the subtype of the feature class to which the filter applies. The Field Order identifies the arrangement of the attributes for display when using the Field Filters table. Field Name identifies the name of the attribute to which the record pertains. The Type Environment attribute identifies the type of control used to set the value of an attribute. These can be 0 (normal drop-down lists for subtypes or domains, calendars for date type attributes, or text input boxes for all other data types), 2 (a pick-list that allows for multiple values from a domain to be selected), 3 (text browsing), or 4 (date picker). The mask attribute controls how attributes are displayed in the PLTS TOC. A value of 0 displays an attribute as normal, 1 disables the attribute from use, 2 makes the attribute invisible, and 3 makes the attribute bold. The Domain Name specifies the name of the domain an attribute is using if applicable. Each of the Field Filter attributes had to be set for each attribute of the eight new features added to the database.

The three geometric representations of the coral reef and MPA features (point, line, and polygon) all used the same Field Filter layout and attributes, with a few exceptions for the point and line features to account for additional PLTS Nautical Solution support attributes. This allowed for the creation of four sets of field filters instead of eight – one for coral reefs, one for MPA and one each for their buffers. Once the filters had been set up for one of the geometric representations of coral reef or MPAs the filter parameters were duplicated and the Subtype Code and Feature Class Name were changed. This was the first step in creating an enhanced editing environment for MEP production.

To create these records, an Access session was started with a copy of the original ENC knowledgebase. The Field Filter table was opened and new entries were added. The information to populate the Field Filter parameters was again a conglomeration of the database schema and MEP specification sheet. The attributes that needed to be displayed for editing and their environment types came from the specification sheet's attribute type entry and the Feature Class Name and Subtype Code names were pulled from the database schema. Additional support attributes were identified in the database and their default filter parameters were applied. Domains were applied to only the attributes that the specification sheet identified as attribute type L. This allowed for multiple values from a defined list (the domain) to populate the attribute as the S-57 encoding guide specifies for type L attributes. Figure 21 shows part of the final Fields Filter table for the coral reef polygon feature.

OBJECTID	Feature_Class_Name	Subtype_Code	Field_Order	Field_Name	Type_Env	Mask	Domain_Name
14187	NaturalFeaturesA	40	1	OBJECTID	0	1	
14188	NaturalFeaturesA	40	2	FCSubtype	0	1	
14189	NaturalFeaturesA	40	3	LNAM	0	1	
14190	NaturalFeaturesA	40	4	NAME	0	1	
14191	NaturalFeaturesA	40	5	DSNM	0	1	
14193	NaturalFeaturesA	40	6	CATREF	0	0	NAUTICAL_CATREF
14194	NaturalFeaturesA	40	7	CRLZNE	0	0	NAUTICAL_CRLZNE
14195	NaturalFeaturesA	40	8	GEOSTR	0	0	NAUTICAL_GEOSTR
14196	NaturalFeaturesA	40	9	COLOUR	2	0	NAUTICAL_COLOUR
14197	NaturalFeaturesA	40	10	NATSUR	2	0	NAUTICAL_NATSUR
14198	NaturalFeaturesA	40	11	NATQUA	2	0	NAUTICAL_NATQUA
14199	NaturalFeaturesA	40	12	NOBJNM	0	0	
14200	NaturalFeaturesA	40	13	OBJNAM	0	0	
14201	NaturalFeaturesA	40	14	pH	0	0	
14202	NaturalFeaturesA	40	15	DISOXY	0	0	
14203	NaturalFeaturesA	40	16	TEMP	0	0	
14204	NaturalFeaturesA	40	17	SALIN	0	0	
14205	NaturalFeaturesA	40	18	LTRNS	0	0	
14206	NaturalFeaturesA	40	19	SUSMAT	0	0	
14207	NaturalFeaturesA	40	20	BACCON	0	0	
14208	NaturalFeaturesA	40	21	BLEACH	0	0	NAUTICAL_BLEACH
14209	NaturalFeaturesA	40	22	DISEA	0	0	NAUTICAL_DISEA
14210	NaturalFeaturesA	40	23	CRNTDR	0	0	
14211	NaturalFeaturesA	40	24	CRNTVL	0	0	
14212	NaturalFeaturesA	40	25	CRLNME	0	0	
14213	NaturalFeaturesA	40	26	INFORM	0	0	
14214	NaturalFeaturesA	40	27	NINFOM	0	0	
14215	NaturalFeaturesA	40	28	NTXTDS	6	0	
14216	NaturalFeaturesA	40	29	PICREP	0	0	
14217	NaturalFeaturesA	40	30	SCAMIN	0	0	
14219	NaturalFeaturesA	40	31	SCAMAX	0	0	
14218	NaturalFeaturesA	40	32	SCAMIN_LOCK	0	0	
14220	NaturalFeaturesA	40	33	TXTDSC	6	0	
14221	NaturalFeaturesA	40	34	RECDAT	0	0	
14222	NaturalFeaturesA	40	35	RECIND	0	0	
14223	NaturalFeaturesA	40	36	SORDAT	4	0	

Figure 21. Field Filter Table for Coral Reef Polygon Feature Class

Once the Field Filters records had been completed for the coral reef polygon feature, the same configuration was used for coral reef points and lines with the addition of PLTS support attributes specifically for points and lines. The records were simply copied and the subtype code and Feature Class Name attributes changed. Using the same filter configuration for all the coral reef subtypes gives a uniform appearance for attribute editing of coral reefs if they are point, line, or polygon geometry.

The same method of combining the database schema and specification sheet was used to create filter entries for the marine protected area (MPA) subtypes of the Regulated Areas and Limits Feature Class and the buffer subtypes.

For the coral reef features specifically, there were 15 attributes that needed to have custom configuration of Field Filter table attributes. The marine protected area features also had 15 attributes that needed custom configuration in the Field Filter table. These attributes for both features correspond to attribute Set A in the specification sheet. Below are examples of the different custom configurations. Some of the attributes needed special configuration because they used multiple values from enumerated lists, single value from enumerated lists, plain text entry, or domain-controlled numerical entry. A full list is available in Appendix D.1. Other attributes from set A, and the attributes from sets B and C identified in the specification sheet, had filters already defined and were used as is for the new features.

Coral Reef Attribute Field Filter Parameter Examples

1: pH: The pH attribute has a Type Environment attribute of 0 for normal text entry, No domain is applied in this table since a range domain is used to control values. The Mask attribute was set to 0 to allow normal display of the attribute.

2: DISEAS: The Coral Disease attribute has a Type Environment attribute of 0 for a selection set from a drop-down menu controlled by the domain identified in the Domain Name attribute (NAUTICAL_DISEA). The Mask attribute was set to 0 to allow normal display of the attribute.

3: CRLNME: The Coral Name attribute has a Type Environment attribute of 0 for normal text entry, No domain is applied to this attribute since it is a string data type. The Mask attribute was set to 0 to allow normal display of the attribute.

Marine Protected Area Attribute Field Filter Parameter Examples

1: BNDCIT: The Boundary Citation attribute has a Type Environment attribute of 0 for normal text entry, No domain is applied to this attribute since it is a string data type. The Mask attribute was set to 0 to allow normal display of the attribute.

2: CONCFS: The Conservation Focus attribute has a Type Environment attribute of 2 for multiple values from a predefined list controlled by the domain identified in the Domain Name attribute (NAUTICAL_CONCFS). The Mask attribute was set to 0 to allow normal display of the attribute.

Master Condition Table Configurations

Modification to the Master Condition table was completed next. The Master Condition table is used by the PLTS application for attribute validation. It extends core attribute validation by utilizing user-defined clauses that compare different attribute values. This allows users to identify and define relationships between attributes that cannot be violated. By way of example, if a coral zone attribute of a coral reef is set to fringe reef and the geomorphic structure of the same feature is set to land, it would be logically inconsistent. Using the Master condition table, constraints on attribute combinations can be identified using a platform independent *where* clause such as the following: If Coral Zone attribute of coral reef 1 is fringe reef and Geomorphic Structure attribute is set to land, then throw error 176.

The Master condition table is also used to identify inconsistencies within attributes. This is necessary since S-57 attribute type L specifies that the attribute can have one or many values from an enumerated list. This attribute type breaks first normal form which the relational database structure of a personal database cannot, unless the data type is text. This presents problems given that with a text data type attribute, domains are not allowed but the domains are needed to house the enumerated list defined in the specification sheet.

Before modifying the table, an examination of the MEP attributes was undertaken to identify functional dependencies between attributes and logical attribute combinations. A list of 13 logical and functional dependencies was developed. The list below shows several examples of logical and functional dependencies between attributes, and a full list is available in Appendix D.2.

Coral Reefs

1: Coral Zone (CRLZNE) and Coral Reef Geomorphologic Structures (GEOSTR) are dependent in that if either one is set to land then the other cannot be set to coral – that is, if one is set to land the other has to set to be land. Also, both are attribute type E, meaning that each is only allowed a single value from a defined list.

Master Condition Trace: 1890, 1891, 1892

Error trace: 167

2: Current Direction (CRNTDR) must have an associated Current Velocity (CRNTVL). If measurements are taken for CRNTVL, CRNTDR measurements are easily recorded.

Master Condition Trace: 1874, 1881, 1882

Error trace: 165

3: Buffer Distance in Feet (BUFDST_FT) is must be equal to 6076 * Buffer Distance in Nautical Miles (BUFDST_NM)

Master Condition Trace: 1889, 1899

Error trace: 170

MPA

1: Consistency of Protection (CONSTY) – If Seasonal or Rotating (value = 2 or 3), then Periodic Start (PERSTA) must not be NULL. If the protection is not year round, there must be a start date for it.

Master Condition Trace: 1897, 1905, 1910

Error trace: 172

2: Consistency of Protection (CONSTY) – If Year Round (value = 1), then Periodic Start (PERSTA) must be NULL. If the protection is not year round, there must be a start date for it.

Master Condition Trace: 1896, 1904, 1909

Error trace: 173

The list was used as a conceptual framework to write platform independent *where* clauses for attribute constriction. Once the clauses were written, the condition identification number from the Master Condition table was recorded and the error to which it linked was also recorded. There were three basic types on clauses written: string comparison, numeric comparison, and multivalue numerical comparison. An example of each is given below; full condition tables are available in Appendix D.3.

String comparison: The attribute value of two string data types must be equal. If the strings are not the same, then an error is thrown (CRLNME <> NOBJNM).

Numeric comparison: The numeric value of one variable depends on the value of another. If one numeric value is *x*, then the other must be or cannot be *y*

((CRLZNE = 12) AND (GEOSTR NOT in (13))).

Multivalue Comparison: The attribute value of one variable depends on the value of another; either attribute can have multiple values. If one attribute value is either *x* or *y*, then the other attribute value must be *a*, *b*, or *nothing* (CONSTY in (2, 3)) AND (PERSTA IS NULL).

Error Table Configuration

Once the Master condition table was configured, error messages were created to inform the user about the violation. Each of the new conditions resulted in error messages being created. The unique ID of the entries in the Error table ties the error message to the condition. The error messages are real-world explanations of the attribute violation. Effort was made to make these error messages as short and informative as possible. The format of the error messages involved providing the name of the attribute from the specification sheet, then the six-letter acronym that is shown in the table. An example would be if the following condition was violated: (CONSTY in (2, 3)) AND (PERSTA IS NULL);As a Consequence, this error message would be shown: Consistency of Protection (CONSTY) is Seasonal (2) or Rotating (3) and Periodic Start Date (PERSTA) is NULL. The conditions are linked through the unique ID of the error and the relationship, look-up, and display of the messages are handled by the PLTS application. Appendix D.4 holds the entire list of error messages.

Topology Rule configuration

Topology rules were built to help constrain geometric editing and assist in preserving geometric coincidence between features. This was essential to produce consistent MIOs. Since the features in ENC cells that are traditionally used to store coral reef and MPA data vary, implementing cross-feature topology rules was not realistic. The best that could be done was to ensure that the multiple representations of features (point, line, and polygon) were overlain properly. This led to the creation of four basic rules implemented between feature class subtypes: Points must be properly inside polygons; polygon boundaries must be covered by line; one polygon must be covered by another polygon; and features must not self intersect or self overlap. Below are three examples of the rules, and a complete list is available in Appendix D.5.

- Coral reef subtype of Natural Feature P feature class (point feature class) must be within coral reef subtype of Natural Feature A feature class (polygon feature class).
- MPA subtype of Regulated Areas and Limits L feature class (line feature class) must be covered by boundary of MPA subtype of Regulated Area and Limits A (polygon feature class).
- Coral reef subtype of Natural Feature A (polygon feature class) must be within coral reef buffer subtype of Natural Feature A (polygon feature class).

The point, line, polygon, and a buffer polygon representational scheme were followed for both of the new features. This allowed for the creation a single set of topology rules that, with subtype name changes. could be applied to all the new features. The implementation of these rules allowed for validation of proper geometry coincidence.

These rules were saved out as a .rul (topology rule file) in ArcCatalog. This allowed the rules to be stored and delivered alongside a database template for use.

Workflow Development

Determining the overall workflow for MIO creation was the product of all three phases. Only on acquiring a practical knowledge of S-57 standards, the final database was designed, and familiarity with how the PLTS application works could development begin. In addition to these understanding, a realistic perception of working with GIS and spatial data was also necessary.

The workflow that was developed as part of the project was intended for an overarching method of MEP MIO creation. The workflow does not document specific button clicks as there are many ways to digitize and integrate auxiliary sources of data for use in MEP MIO data. Instead this workflow documents the general steps to be followed for MEP MIO creation and are general enough that with minor modification, they could be extended for MIO creation of all types.

The development of these workflows followed implementation and testing. Discovering how to implement the creations from the previous phases provided insight into the best ways to create MEP MIOs and how to use PLTS to do so. In figure 22, the workflow for MEP MIO creation is documented. It begins with finding of areas that need auxiliary information in ENC cells as well as the discovery and integration of additional data sources. The workflow moves through the six main processes of creating MEP MIO: integrating external and digitized data into S-57 format, attribute validation, geometric validation, updating primitives, and export to S-57 formatted MIO. Recommendations are made within the workflows regarding best practices of data integration and storage.

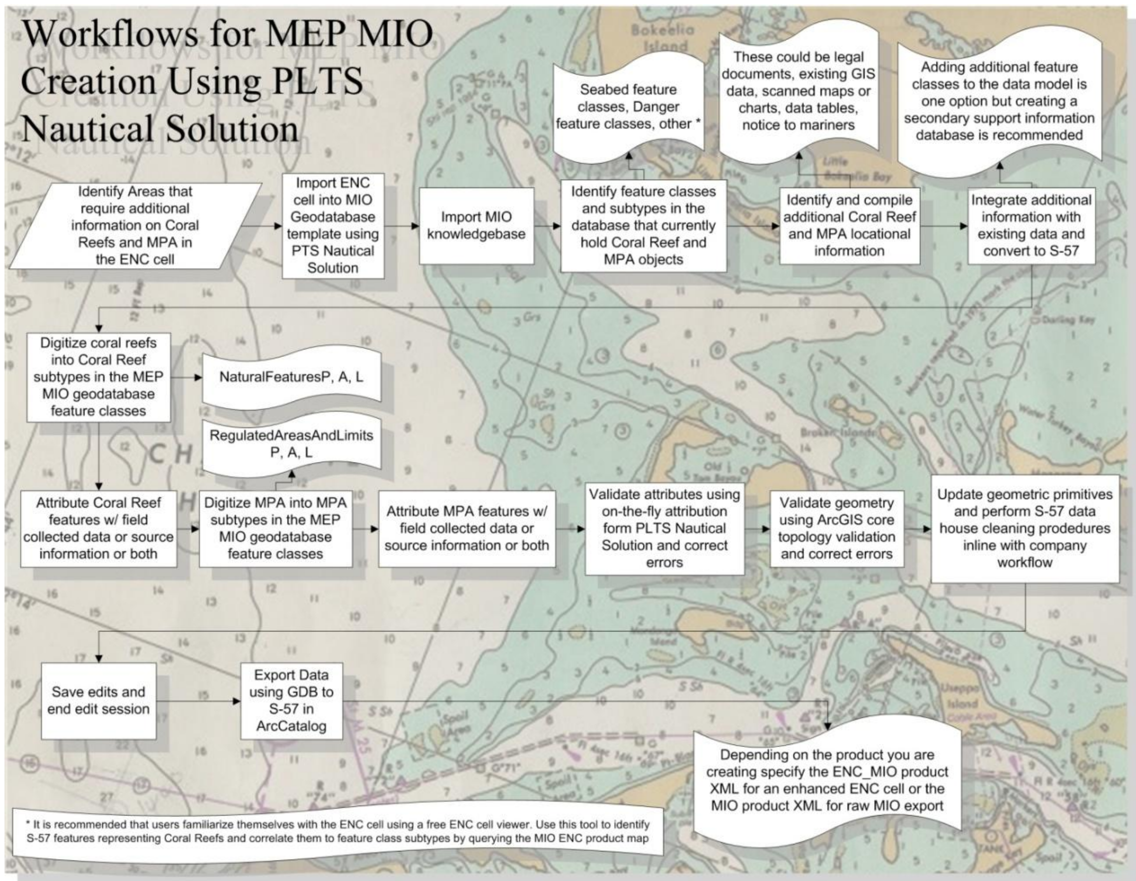

Figure 22. MEP MIO Creation Workflow

5.3. Testing

The implementation and testing of the products conceived in the design phase and brought to fruition in the creation phase proved to be a difficult task. There were three main areas to test: import functionality, export functionality, and the constraints for editing and creating MEP MIO data and MIOs. This section is broken down into three sections that reflect this phased testing and implementation process. Since the approach to implementation, testing, and creation took was iterative, changes were made to products and deliverables that had been previously accepted by the client. The changes made as a result of testing and implementation, as well as the efforts to bring all the parts together, is documented below.

5.3.1. Import Functionality Implementation and Testing

In order to test the functionality of the system, ENC first data was needed. This allowed for implementation and testing of the import functionality. To test this product, the XML schema file for the entire database needed to be accessible by the PTS application. Per the PLTS Nautical Solution structure, additional entries were added into the products configuration file first. These entries specify the name and the product specification (PRSP) value of the product XML schema. The PRSP value defined for MIO is 60 and was applied to the new entry as it had been to the database model. Once this modification was in place an import of S-57 data was executed. Before the importer interface was entered an error was received, specifying that the product configuration could not be loaded.

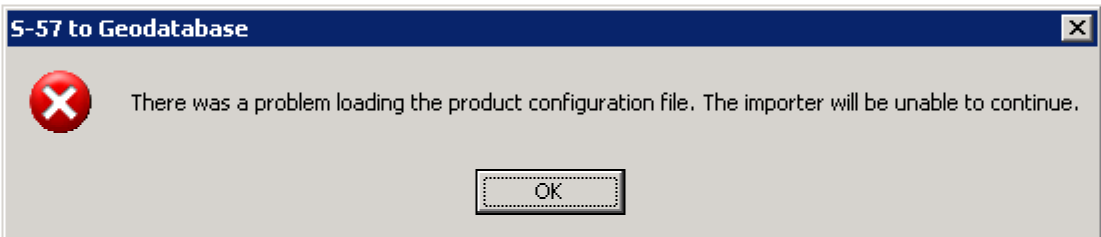

Figure 23. Error Message Received During Export

This prompted an e-mail message to be sent to the technical lead on the project. After some discussion, it was discovered that there was another database that needed to be configured so that the PLTS application could point to the correct product XML schema. The info database had another entry recorded that specified the MIO product XML schema location, name, and global unique identifier that was specified in the XML. At this point, another test on import functionality was executed. This resulted in the same error being thrown. After several more tests to no avail and a discussion with the PLTS developers and technical lead, it was determined that the PRSP values in PLTS Nautical Solution were hard-coded and that even though the PRSP and GUIDs were located in the right tables, databases, and configuration files, PLTS was not able to access them for import export functionality.

In order to get the import functionality to work, the MIO database template PRSP values were changed to 1. This is the number for the ENC product that was specified in the info database and product configuration files. The name of the new XML schema file was changed to that of the ENC schema file and the GUID was changed to match, as well. In effect, what was happening was that PLTS thought that it was looking at a standard ENC XML schema file but, in fact, was pointing to the new one. With this workaround in place, access to the product configuration file was allowed by PLTS and importation of an ENC cell into the new database was still unsuccessful.

This prompted a thorough examination of the XML schema files produced. Several syntactic, numbering, and attribution errors were discovered. Changes were made in the Object Map element's attribution of several object maps. Spelling errors in several of the tags were corrected and object map and attribute map IDs were corrected. Again, this resulted in failed import on ENC data.

The second approach to implement this functionality was to use computer-generated code in the import/export XML schema file. This was accomplished by modifying the existing S-57 configuration file and using an ESRI in-house software product that compares such schema with that of a geodatabase. The geodatabase template created during logical modeling was used along with the newly modified S-57 XML. The proprietary software produced a product map that looked exactly the same as the one previously created, but with no human errors. The relevant object maps that represented the new features in the database were copied and pasted into the existing MEP MIO XML schema file over the same entries. With this new product configuration file created and the workaround in place, import functionality was tested again. This resulted in ENC data being successfully imported into the geodatabase template using the MEP_ENC product map.

This demonstrated that existing ENC cells could be brought into the new geodatabase template for use in creating MEP MIOs and assuring proper coincidence. The next step was to test the importation of an MEP MIO. To test this functionality, first an MEP MIO in S-57 format needed to be created. As discussed in Export Functionality Implementation and Testing (section 5.3.3) this point was not reached for several reasons and testing of this functionality could not be completed.

5.3.2. Knowledgebase Implementation and Testing

The knowledgebase implementation was straightforward. The PLTS application has a tool for loading the knowledgebase tables into a designated database. Once data had been loaded into a database template, the Load Knowledgebase tool was executed. This populated the database with the tables configured during the knowledgebase creation phase. These tables – specifically the Fields Filter, Master Condition, and Error tables – were necessary to provide the computer environment that would be conducive to consistent production and reproduction of MEP MIO data and MEP MIOs.

With knowledgebase tables loaded into the database, testing of the Field Filter, Master Condition and Error table ensued. The testing procedure called for digitization of coral reef and MPA features, followed by attribution and validation. To test the functionality, new features were loaded into an ArcMap edit session (initially, these features were in the point feature class for coral reefs). With the data loaded, a single feature was created and the PLTS Selection tab in the Table of Contents was selected. The resultant view provided proof that the Field Filter table was working properly. Figure 23 shows the filtering applied to the attributes on the PLTS Selection tab. Grey attributes have been masked out so they cannot be edited. Also shown is a drop-down box supplying allowable values from an enumerated list in accordance with S-57 specifications for type L. This is controlled by setting the Field Filter Type Environment attribute to 0 and specifying a domain. The second image shows how specifying an environment type of 2 and a domain in the Field Filters table allows for multiple values from an enumerated list to instantiate an attribute.

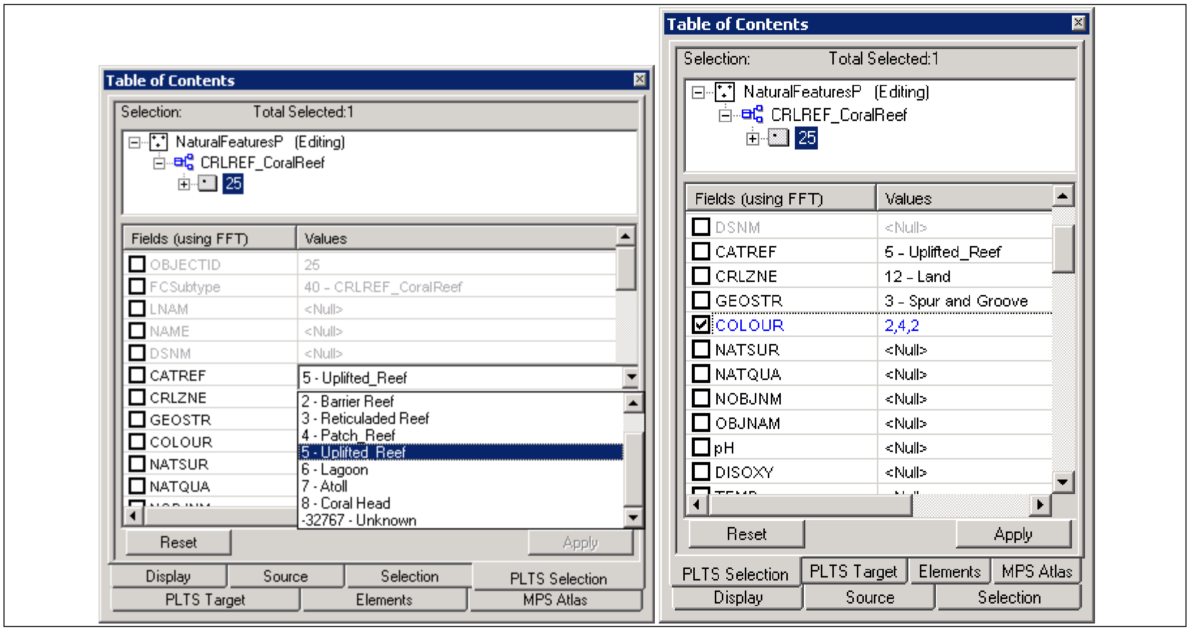

Figure 24. Implementation of Field Filter Table

This same method of opening the individual feature classes, digitizing a feature into the proper subtype, then selecting and viewing the attributes available and observing their behavior on the PLTS Selection tab was followed for all the features. Only one modification needed to be made to this table as a result of testing. This was to the attributes that utilized a range domain. Originally, a domain was specified in the attributes that were using a range domain. When this configuration was used in ArcMap, a list of values was supplied in a drop-down menu showing all possible values. This list was quite unwieldy for several of the larger ranges. To remedy this, the domain specified in the Field Filter table was removed for attributes using range domains. This fixed the problem of lists of all allowable values in a range domain being shown in a drop-down menu. The modification took attribute value control away from PLTS for attributes using range domains. The problem was remedied through the use of conditional statements in the Master Condition table that bounded allowable number ranges and provided PLTS control over these attributes. Testing was reexecuted on the feature classes and the proper functionality of the Field Filter table was achieved.

After Field Filter table testing had been completed, testing focus shifted to the Master Condition table. To test the configurations made to this table, the initial steps for testing the Filed Filter table were followed. This brought the MEP MIO feature class subtypes into ArcMap, opened them for editing, and created new features. Testing began with polygon features of coral reefs and MPA. When first testing, most of the *where* clauses did not work. This was the result of bad syntax in most cases. At this stage, errors were mainly indicating mixed data types and operators or invalid syntax (using unrecognized commands or operators or invalid use of qualifiers such as AND, NOT, OR, and IN).

It took several iterations of syntax before valid clauses were created. Initially there was speculation about the PLTS application being hard-coded with an upper bound for attribute validation. If true that would mean the subroutine that controls attribute validation through the Master Condition table can only go through so many iterations due to a programmed limit. This was presumed to be the case when all clauses were determined to be syntactically correct by entering them into the table with UIDs lower than 900.

To resolve this issue, functionality testing moved toward diagnostic testing. All conditions in the Master Condition table were removed except for those pertaining to the coral reef or MPA feature class subtypes. This truncated Master Condition table was loaded into a separate geodatabase template that was populated with data from an ENC cell. When attributing the polygon features (per the testing strategy) with this version of the Master Condition table, the attributes were still not properly constrained through PLTS on-the-fly validation. However, when using the Data Reviewer validation from the core PLTS extension, the attribution was properly flagged with errors, although the values were initially permitted. This prompted the next phase in attribute constraint testing – point and line testing – to be initiated early.

Upon performing tests on attribute constraints for point and line features using the truncated Master Condition table, the results were quite positive. The clauses created for these features were executing properly, constraining edits, and throwing the appropriate errors. This was very puzzling but it supported the hard-coded loop theory, in as much as they had not worked previously. To test this theory again the records for point, line, and polygon conditions were copied into a new knowledgebase and reloaded into a geodatabase. The same testing approach was used, this time starting with point and line features. With a fully loaded knowledgebase, the point and line conditions were working properly (constraining attribute value entry to lists, throwing proper errors when conditions violated, and not permitting attribute values from being saved). This decidedly disproved the hard-coded loop for validation theory as the ID number for the conditions exceeded the hypothesized upper bound. When testing on polygon features while using the fully loaded Master Condition table, the same results were seen, conditions not throwing the corresponding errors and allowing inappropriate values. These results have led to the belief that there is an error in the software that is applying polygon validation conditions differently from those of points and lines.

These results concluded the testing on knowledgebase configurations. A more thorough discussion on the results can be found in Chapter 6.

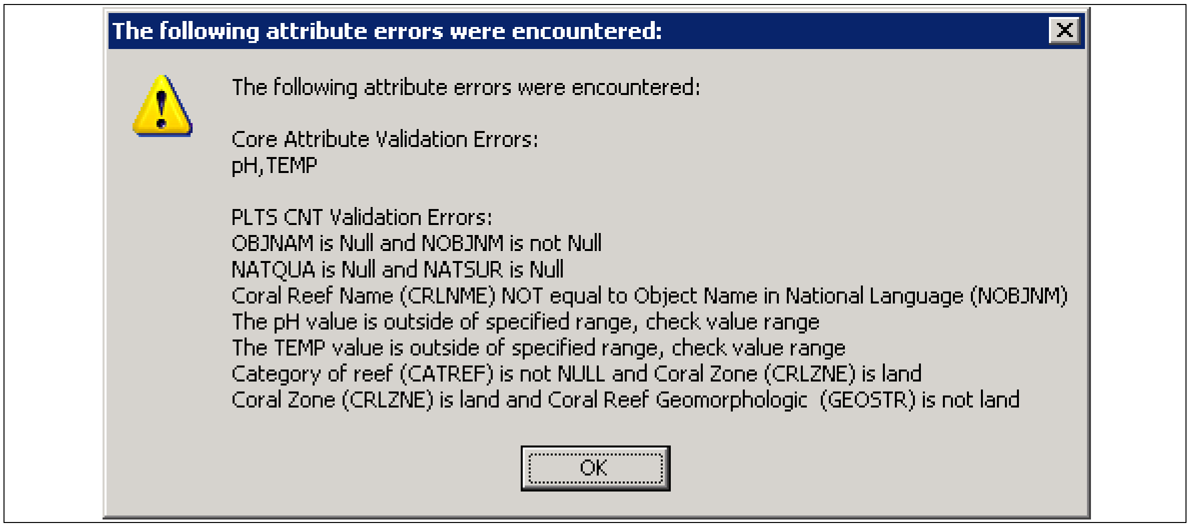

Figure 25. Error Messages Displayed When an Attribute Condition is Violated

5.3.3. Export Functionality Implementation and Testing

The final stage in implementation and testing was to examine export functionality. The same XML files used for importing data are used for exporting, since the object and attribute maps in the document can be read both ways. To test this functionality, the procedures for the previous two testing tasks were followed. This loaded data into a geodatabase template, brought the data into an ArcMap session, opened the data for editing, created new features, and attributed them.

Vital in being able to export data to S-57 format is adherence to the point-set topology data structure specified by S-57. In order to facilitate this, topology rules were created and loaded into the database. These rules consisted of the ones developed for this database and the existing ENC topology rules. When topologic validation was run initially, there were 230 errors. These errors were corrected, then testing proceeded with feature creation, attribution, and validation.

With the rules in place, new features added to database, and features attributed, a specific command in the PLTS Nautical Solution needed to be run – the Update Primitives tool. From the ESRI PLTS Help documentation "In addition to the standard reconcile function, Update Primitives validates topology, updates geometric primitives, and if set, removes unnecessary vector connected (VC) nodes. Essentially, it builds and maintains the necessary topological information to support S-57 products" (2007). When this tool was run the process seemed to execute properly. When an attempt was made to export the database to an enhanced ENC cell, an error occurred stating that edits had been made and primitives needed to be updated. This was incorrect and diagnostic testing followed.

To determine the cause of the error, a test was run on the database itself to make sure that geodatabase alterations were not affecting the export. Without making any edits to the database after an ENC cell was imported, the database was reexported. This resulted in a successful export of the database. This led to the belief that the database schema was not affecting the export and the issue was with the data entries and the application.

To determine if this was the case, the Update Primitives tool was bypassed and an export was attempted. To bypass the “update primitives” error there is an attribute of the PLTS Products table that identifies whether or not edits have been made. This attribute is controlled by the Update Primitives subroutine discussed earlier. When the subroutine is run, it flips the Edits Made attribute to false, which is turned to true when an edit session is started. This attribute was manually changed in Microsoft Access and an attempt was made to export the data.

When the topologically validated and attributed database was exported, another error was encountered. This error specified that an entry in the SREL table did not have the two associated entries. This table maintains the relationship between the vector primitives and the feature class geometry. Any error in this table will not allow proper construction of the S-57 formatted ENC cell. The issue is that the Update Primitives tool was not properly updating the new features and the SREL table. This is the reason why the Edits Made attribute in the PLTS Product table was not flipped to false. No indication of this error was given when Update Primitives was run. This caused the export to fail every time. Determining why the Update Primitives tool does not correctly update the features and the tables is outside the scope of the project and export functionality implementation and testing was forced to end here.

6. Results

This project sought to create an extended ArcGIS application conducive to consistent production of Marine Environmental Protection Marine Information Overlays in S-57 format. To accomplish this, ArcGIS PLTS Nautical Solution was configured to perform the necessary functions to constrain attribution and ensure geometric coincidence. Additionally, the database was customized to store MEP data, and an overall conceptual workflow for MIO creation was developed. This chapter documents the results from these configurations and the functionality that was achieved.

The functional requirements described in Chapter 3 break down into two general categories: import/export functionality and feature creation constraint. These requirements were met through configuring XML files, database models, and the PLTS knowledgebase.

To meet the import requirement, modifications were made to the XML configuration file used by the PLTS application. The modifications made to the XML document allowed import of existing ENC cells into the database. This, in turn, allowed ENC data to assist MIO production and ensure coincidence of the data. The only issue encountered and unresolved is that the product value (PRSP), specifying XML documents for specific products in the PLTS application, are hard-coded. This means that the PRSP value in the database and the name of the XML document for import has to use existing names and values. This is a stopgap measure as PLTS does not have the functionality to add PRSP values and XML documents to the solution. This means that full functionality has been reached but the means for doing so are not readily available in the PLTS application. The long term result is that extension of PLTS Nautical Solution for the creation of other nautical products is not feasible outside of ESRI development since source code is not available.

Three modifications were made to meet the constriction of attribution and geometric coincidence requirement (database creation, knowledgebase configuration, and topology rule implementation).

A new database model was created that allowed for storage of ENC and MIO data together. This integration of features allows ENC data to inform the creation of MIO data. This is essential for proper data coincidence (since these datasets will be overlaid during use) and because ENC cells contain a variety of coral reef and MPA data. A geodatabase model was created from this model for dissemination and use within ArcGIS and the PLTS Nautical Solution. This allowed the MIO and ENC data to work together and ensure coincidence of geometric representations through ArcGIS functionality and, in doing so, fulfilled the functional requirement for data storage and information sharing. To ensure proper data coincidence, topological rules were created and implemented in the ArcGIS geodatabase through core ArcGIS functionality. Topology management is controlled by ArcGIS. This means that the topologic rule validation (insuring that the rules are adhered to and flagging topological errors) is maintained by the application and no configuration for implementation was necessary.

To constrain attribution of features, the ENC knowledgebase was configured by modifying several of the tables (Master Condition, Error, and Field Filter tables) in the existing knowledgebase that created a new knowledgebase applicable to MEP MIO. These modifications worked properly to constrain edits for all point and line features in both the coral reef and marine protected area subtypes. This means that the conditions for attribute control defined in the Master Condition table properly constrained attribute values; the Field Filter table disabled and enabled the proper attributes for editing; and when a condition was violated during on-the-fly attribute validation, the Error table threw the proper error and edits to attributes were not committed to the database. For the polygon subtypes of both coral reef and marine protected area, the conditions for attribute control did not work properly during on-the-fly attribute validation. When erroneous attribute values were entered, PLTS on-the-fly validation did not catch the errors and permitted the values were committed to the feature table. However, when PLTS Data Reviewer was run, the errors in attribution were flagged. This is the result of errors in the PLTS application code according to discussions with the client.

Export functionality was not reached. The export functionality has been thoroughly tested, and the final diagnosis for failure is the PLTS Nautical Solution application. The software failed to properly update PLTS controlled attributes which are necessary to maintain the connection between geometric primitives and feature geometry. When the Update Primitives tool was run, the records for geometric primitives were inserted into the SREL table, but the attributes that linked those records to feature geometry were not properly updated. This caused a mismatch in the table since the linking attributes have no values. The result is that this causes the export engine to fail every time an export was attempted. This is a documented and known problem with PLTS Nautical Solution at the 9.2 build. It was decided in consultation with the client that fixing this problem was outside of the scope of this project.

7. Conclusion

This project examined and extended the current abilities of the Environmental Systems Research Institute's PLTS Nautical Solution to make it viable for MIO creation. This project focused on three aspects of ESRI products for extension or modification: (1) the Electronic Navigational Chart (ENC) data model, (2) the data interoperability capabilities between the native ENC data format (S-57) and ESRI's geodatabase, and (3) the data management and maintenance capabilities of the Production Line Tool Set (PLTS) Nautical Solution to deal with the consistent production of this data. Each of these aspects was successfully configured within the means and scope of this project. Where implementation fell short of its goals, diagnostic testing provided insight to the cause of failures and provided valuable feedback to the client on the software and the ease with which the software can be extended.

The specification sheet was a key component to completion. It was used in almost all aspects of software configuration. The conclusion for this aspect of the project is that when any modification of this type is undertaken, a significant amount of time must be taken to create these documents.

It was determined that modification of the PLTS Nautical Solution is much more complex than previously thought by the client. Difficulty with extensive XML documents, hard-coded values, limited documentation, and software glitches makes modification by a third party difficult, and in some, cases impossible. However, the fact that this turnkey solution can be modified is impressive considering the inflexibility of other specific solutions by other vendors.

For Marine Information Overlays answering the need for additional marine information, there utility is questionable. Mariners and navigators have been using nautical charts composed of critical information for navigation for years. Providing additional information that is not critical for them will go unused. Marine Environmental Protection MIOs have little bearing on the navigational tasks at hand. Some of the MIOs such as Ice Coverage, and Tides and Variations could be of use to navigators and provide better information for safety and ship routing.

For marine conservationists this method for providing additional marine information is of great use. Standard measurements and storage of data provides this users group with environmental data for analysis and environmental monitoring. This allows for better management of coral reef and marine protected for the future.

Overall, MIOs for the mariners are not the best means to communicate additional marine information but does provide marine conservationists with standardized data for analysis across systems, time and geographic boundaries.

7.1. Further Work

From this project several others can be spawned. The project would be to fix the code errors to make PLTS friendlier for new product configuration. This would allow PLTS to become more flexible for modification. It would entail a thorough review of the source code of the application to identify hard-coded values, then modifying them to be more flexible. Another step in this project would be the creation of user interfaces to allow for an interactive selection of products to be created instead. Determining the causes and fixes of polygon attribution would provide the required functionality to consistently produce MIO data.

The second project would be to perform spatial analysis based on the extended attributes in the specification sheet and dynamic feature creation. This would take the additional attributes in the specification sheet for marine conservationists and define standard analysis techniques for environmental modeling. This project could also incorporate models used to build features according to current features or attribution.

The third project would be to extend this work to other or all MIOs. This project would develop a single database for all MIOs. This would incorporate all of the aspects of the project described herein but taking it to the next level. This project would seek to develop a single database to store all features for all MIOs and provide the means to export individual MIOs for decision support and use on ECDIS.

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